SURFACE TEXTURE (PROFILE) MEASUREMENT

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OFFSHORE POWER SYSTEMS DIVISION
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FOREWORD

This research project was performed under the National Shipbuilding Research Program. The project, as part of this program, is a cooperative cost shared effort between the Maritime Administration and Avondale Shipyards, Inc. The development work was accomplished by Offshore Power Systens under subcontract to Avondale Shipyards. The overall object of the program is improved productivity and, therefore, reduced shipbuilding costs to meet the lower Construction Differential Subsidy rate goals of the Merchant Marine Act of 1970.

The studies have been undertaken with this goal in mind, and have followed closely the project outline approved by the Society of Naval Architects and Marine Engineers' (SNAME) Ship Production Committee.

Mr. Benjamin S. Fultz of Offshore Power Systems, served as Project Manager and principal investigator. On behalf of Avondale Shipyards, Inc., Mr. John Peart was the R & D Program Manager responsible for technical direction, and publication of the final report. Program definition and guidance was provided by the members of the 023-1 Surface Preparation Coatings Committee of SNAME, Mr. C. J. Starkenburg, Avondale Shipyards, Inc., Chairman.

Also we wish to acknowledge the support of Mr. Jack Garvey and Mr. Robert Schaffran, of the Maritime Administration. Special thanks are given to Mr. William E. Drews of Rank Precision Industries, Inc., for the numerous measurement performed using a stylus type instrument and to the other suppliers listed below for their valuable contribution of information.

- •irtronics
- •endix Automation and Measurement Division
- •Marduth Products
- •Harper Electro-Deburring Co.
- •Alince Corporation
- •Rank Precision
- l Ervin Industries

- Wheelabrator Frye
- Gar Electroforming Division, Mite Corporation
- Elektro-Physik, Inc.
- Elcometer Instruments Ltd.
- Textex Inc.
- Sentec Corporation
- Nikon
- Calspan
- Flexbar
- Hacker Instruments, Inc
- Bausch and Lamb
- Zeiss
- KTA - Ken Tator Associates
- Mass Instruments

Executive Summary

In recent years there has been much ado concerning the measurement of surface profile (texture). Many painting specifications have been written to require exact profile heights with no reference being given to the method of measurement. To further complicate the situation, profile height is not a readily adjustable manufacturing process. In fact, the only method of adjustment is to change surface preparation procedures, e.g. , change abrasives for blasting. Since most abrasives are only regionally available and not subject to standardization, this could leave the shipbuilder in a dilemma.

AS was found during this study, many techniques exist for measuring surface texture (profile). Each gives a different average measurement with some overlap within the range of measurements. The most important observation concerning these measurements was that none is precise due to the random nature of the surfaces prepared for painting. To preclude these problems, future paint specifications, if referencing required profile heights, should specify the measurement techniques with a wide range of acceptable values.

From a paint performance stanpoint, the most important factor is to insure that the surface texture is completely and adequately covered with paint. This can be accomplished using a readily available, standard shipyard measuring device, namely, a magnetic (snap-off) gauge routinely used for measuring paint dry film thickness. This same gauge can be used to “factor in” surface texture when measuring actual dry film thicknesses.

In addition to the magnetic gauge, two other gauges are suitable for measuring relative surface texture under shipbuilding conditions. These are as follows:

- Replica Tape/Dail Indicator (Testex)
- Manual Stylus Instrument (Elcometer 123)

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1. CONCLUSION

1.1 Project Results

The purpose of this project was to determine the availability of various surface texture (profile) measuring methods and instruments and to evaluate their suitability for use under shipbuilding conditions. To accomplish this goal, a survey was made of the requirements as shipbuilders saw them from a use standpoint, and a survey was made of the technical community to identify possible candidate measuring methods, procedures and instruments. Following these surveys, a laboratory test program was formulated and carried out to substantiate suitability of use under shipyard conditions and to tabulate the various measurement results.

The project goals were successfully achieved. Section 3 of this report contains a detail evaluation of each process and Section 4 contains the laboratory measurement results.

As found during the course of the study, there are three attributes of surface texture which must be understock prior to evaluating measurement techniques. These measurement attributes are lay, waviness and roughness. Of these, paint people are most concerned with roughness.

At the beginning of the project, it was assumed that an exact mathematical relationship could be developed and implemented to convert from one method to another to form a baseline of communication. No such relationship could be found due to the extra random nature of the prepared surfaces.

of those instruments tested, three were found to be compatible with shipyard painting operations. These are:

- Magnetic (Snap-Off) Gauge
- Replica Tape/Dial Indicator (Testex)
- Manual Stylus Instrument (Elecometer 123)

It must be remembered that when using any of these instruments, none make precise measurements. Only average surface texture (profile) height with a large data spread is obtained.

Even though average profile heights can be measured, the profile height can only be adjusted by changing the type of abrasive used to clean the surface. This can be accomplished by specifying the size, hardness and density of the abrasive.

One of the most important factors in paint performance is to insure that the surface texture is completely covered by a minimum amount of paint.[4,7,9,14] One method for insuring adequate surface coverage is to measure the surface texture with a standard snap-off magnetic dry film thickness gauge.[10] This is accomplished by measuring the surface texture after cleaning but prior to painting. The measurement obtained does not give actual profile height but rather a number which represents the texture. The paint is then applied in such a manner that the measured dry film thickness exceeds the minimum specified by the surface texture measured value. In other words, the resultant dry film thickness would equal the specified mount plus the measured surface texture.

Limited testing was also performed in an attempt to determine a relationship between profile height and paint performance. No relationship could be found. The most important performance determinant was surface cleanliness and adequate film thickness.

In conclusion, surface texture measurement is not a precise science as it relates to surface preparation for painting. Surface texture can only be controlled by the surface preparation procedure and/or abrasive selection and is not readily adjustable. As long as maximum abrasive sizes are specified, no significant paint performance differences should result from m the variance in surface texture.[14]

SECTION 2
Project Plan of Action

2. PROJECT PLAN OF ACTION

2.1 Introduction and Background

2.1.1 Objective

The objective of this project is the determination of profile measurement instruments/techniques best suited to shipyard production methods and the correlation of various measurement results using the must promising instruments/techniques.

2.1.2 Technical Background

When steel surfaces are prepared for painting, either mechanical or chemical forces are applied to condition and/or clean the steel substrate. This external force alters the surface and creates a new surface topography or texture. Many scientific instruments and methods exist for measuring the created surface Characteristics. Most techniques have been adapted from machining technology.

In 1978, a standard was written by the American National Standard Institute, “Surface Texture - Surface Roughness, Waviness and Lay", ANSI B46 .1-1978.6 This standard governs “the measurement of geometric irregularities of surfaces of solid materials, physical specimen for gaging roughness and the characteristics of stylus instrumentation for measuring roughness. ” The standard contains a review of various instrumentation and methods but primarily specifies the requirements of stylus type instruments. Even though written primarily for machining type applications, the standard contains many definitions which can be directly adapted to surface preparation operations. These standard definitions are listed below.

- Surface Texture - The repetitive or random deviation from the normal surface which form the three-dimensional topography of the surface. Includes roughness, waviness, lay and flaws.
- Lay - Lay is the direction of the predominant surface pattern.

- Waviness - Waviness is the more widely spaced component of surface texture. Unless otherwise noted, waviness includes all irregularities whose spacing is greater "than the roughness sampling length and less than the waviness sampling length. Roughness may be considered superposed on a "wavy" surface.
- Roughness Roughness consists of the finer irregularities which result from the irherent action of the production process.
- Flaws - Flaws are unintentional irregularities Which occur at one place or at relatively infrequent or widely varying intervals on the surface. Unless otherwise specified, the effect of flaws shall not be included in the roughness average measurements.
- Profile - The profile is the contour of the surface in a plane Perpendicular to the surface.
- Manual Profile - The normal profile is a profile of the normal surface.
- Measured Profile - The measured profile is a representation of the profile obtained by instrument or other means.
- Modified Profile - The modified profile is a measured profile where filter mechanisms are used to minimize certain surface texture characteristics and emphasize others.
- Graphical Centerline - The Graphical centerline is the line about which roughness is measured and is a line parallel to the general direction of the profile within the limits of the sampling length, such that the sums of the areas contained between it and those parts of the profile which lie on either side are equal.
- Peak- A peak is a point of maximum height on that portion of a profile which lies above the centerline and between two intersections of the profilele and the centerline.
- Valley - A valley is the point of maximum depth on that portion of a profile which lies below the centerline and between two intersections of the profile and the centerline.
- Roughness Spacing - The roughness spacing is the average spacing between adjacent peaks of the measured profile within the roughness sampling length.
- Sampling Length - The sampling length is the nominal spacing within which a surface characteristic is determined.

- Roughness Sampling Length (cutoff) - The roughness sampling length is the sampling length within which the roughness average is determined.
- Height - Height is considered to he those measurements of the profile in a direction normal to the nominal profile.
- Roughness Average (RA) - Roughness Average is the arithmetic average of the absolute values of the measured profile height deviations taken within the sampling length and measured from the graphical centerline. (Formally designated AA)
- Peak-to-Valley Height - the peak-to-valley height is the maximum excursion above the centerline, plus the maximum excursion below the centerline within the sampling length.
- Root Mean Square (RMS or R_q) - the square root of the squares of the means of the values.
- Peak Count (PC) - The nunber of peaks exceeding a certain height or pro jetting above a pre-determined reference line, or the number of peak/valley pairs pro jetting above and below two pre-determined reference levels.
- Maximum Peak to Valley Height (Rmax) - the largest peak to valley height of a profile in one sampling length.

Figure 2.1 contains a pictorial display of the defined surface characteristics. These definitions will be used throughout the report.

As can be seen from this diagram, the primary components of surface texture are lay, waviness and roughness. Lay primarily results from the direction of the machining operation and is and generally experienced in surface preparation operations. Therefore, the waviness and roughness are the must important attributes. Waviness is a macro measurement and the normal waviness spacing would be approximately 1/8 inch. Roughness is a micro measurement and normally equals approximately 0.030 inch (30 roils). Many parameters can be measured within roughness. These include, roughness average (RA) and peak-to-valley heights. Flaws are another consideration and would probably equate to things like pits on rusted surfaces. A complete understanding of these definitions and their relationships to one another is absolutely necessary prior to evaluating surface texture measurement techniques, procedures and instruments.

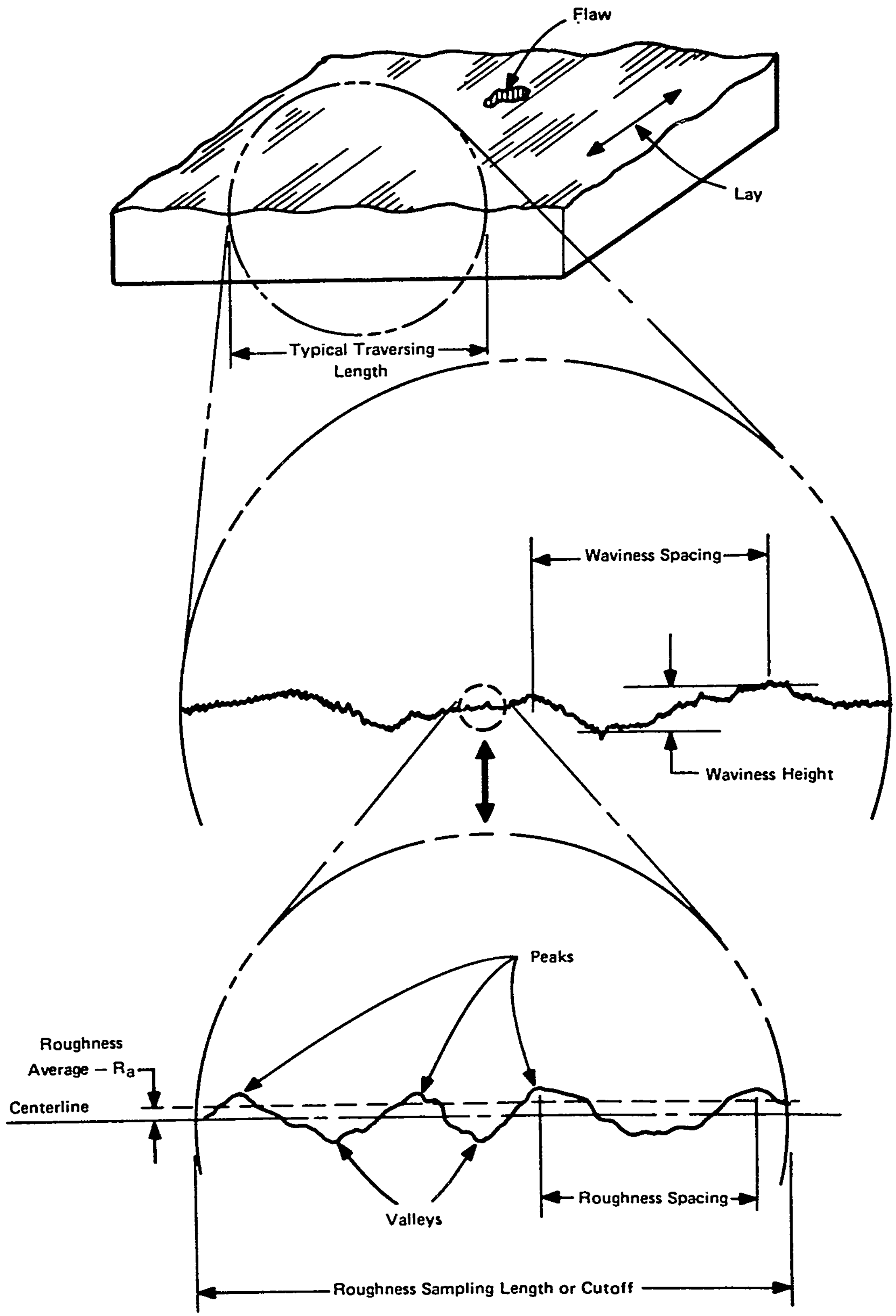


FIGURE 2.1: PICTORIAL DISPLAY OF SURFACE CHARACTERISTICS

The Steel Structures Painting Council has proposed a simlified method of characterizing surface texture. The proposed method describes the average maximum peak to valley (Rmax), the degree of cleaning and the type of surface texture. The five categories of surface texture are:

- Type A- Smooth cusps end well defined craters; produced by round shot.
- Type B - Similar to Type A, with many well defined craters, but having irregular shapes and sharper peaks; generally produced by steel grit.
- Type C - very irregular, highly disturbed, almost no smooth cusps or rounded craters, choppy; produced by sand and some other non-metallic abrasives.
- Type D-Half the mill scale remaining and a fine type C surface where the mill scale has been removed, characteristic of “Brush-Off (SP7)” grade blast regardless of abrasive type.

When discussing the measurement of surface texture (topography), it must be remembered that many factors go into the creation of a surface characteristic; namely, the hardness of the steel substrate, the size, hardness, morphology, density and velocity of the abrasive, and the angle of impact between the substrate and the abrasive, the length of time of exposure to the cleaning process, and the type of surface preparation technique and equipment.[3,8,10,11]

One other aspect of surface characterization which has not been discussed is the degree of cleanliness. Many standards already exist for this attribute, and therefore cleanliness will not be addressed as such in this report. However, the degree of cleanliness will be defined when presenting measurement results.

To further complicate the problem of surface texture measurment, most of the existing instruments provide a measurement which is not directly convertible to a measurement provided by other instruments. As will be seen in the body of this report, these measurement results are widely divergent. In addition, numerous surface preparation and painting

specifications and standards specify precise profile limits neither defining profile terms nor making reference to an exact measurement technique. Therefore, an utmost need exists to create a profile or surface texture measuring concensus standard through a technical organization such as ASTM Committee F25.02.

Shipbuilding surface preparation techniques are generally limited to the following:

- Abrasive Blast (Pneumatic and Centrifugal)
- Power Tool Cleaning
- Chemical Cleaning

For this reason, the research effort was limited to measuring profile resulting from these techniques.

2.2 Plan of Action

To accomplish the defined objectives of this project, the study was divided into four distinct tasks.

- Formulate Shipbuilding Requirements for Surface Texture Measurement Instruments and Methods
- Survey and Identify All Known Surface Texture Measurement Instruments and Methods
- Complete a Laboratory Test Program Designed to Evaluate Various Instruments and Tabulate Results
- Recomend Favorable Method(s) and Instrument(s)

2.2.1 Formulation of Shipbuilding Requirements for Measurement Instruments and MethodS

Through formal and informal discussions with other marine construction and shipbuilding personnel, the following requirements were formulated:

- Rugged, Durable Construction

- Easy and Simple Calibration
- Self Contained, No Electrical or Other Services Required
- Simple to Read, Requires No Interpretation
- Gives Only Needed Information, Not Highly Technical
- Inexpensive and Available
- Light Weight
- Repeatable Results

2.2.2 Survey and Identification of Known Surface Profile Measurement Methods and Instruments

Immediately after project start, an extensive survey was completed consisting of the following:

- Literature Search
- Computer Assisted Search
- Formal Contact with Scientific Instrument Manufacturers
- Formal and Informal Discussions with Experts

The bibliography contains a list of referenced documents and the Foreword contains a list of equipment suppliers.

2.2.3 Formulation and Completion of a Laboratory Test Program

The laboratory test program consisted of the following activities:

- Selected two types of steel (A-36 and HY80) representative of normally used ship steel.
- Selected representative surface preparation techniques (Abrasive Blast, Power Tool Cleaning and Chemical Cleaning).
- Selected types and sizes of abrasives, wire brushes, sanding discs, chemicals, etc., normally used in shipbuilding.
- Defined cleaning parameters based on shipbuilding requirements to include power tool speeds, blast pressures, angles of attach, abrasive wheel horse power, etc.

- Cleaned the two types of selected steels using the various techniques according to defined parameters.
- Measured resulting profiles using the available instruments. This part of the test used standard averaging techniques to assure unbiased data.
- Evaluated each instrument and method using the criteria identified within paragraph 2.2.1.
- Recorded and tabulated measurement results in matrix format (see Tables).
- Selected the scanning electron microscope (SEM) to provide an exact visual picture of each prepared surface texture. Annex A contains photomicrographs of each prepared surface.

Section 4 of this report contains the results of the laboratory test program.

2.2.4 Recommendation of Favorable Method(s) and Instruments)

Based on the results of the laboratory test program and the evaluation of instruments against the parameters as established in paragraph 2.2.1, the following equipment is recommended for shipyard use:

- Testex Replication Tape with Dial Indicator Calibrated to Read Measured Profile
- Elcometer 123 Calibrated to Read Measured Profile
- Magnetic Snap-off Gauge (Microtest or equal)

As will be seen in the body of the report, the measured values obtained y each of these methods vary according to the method employed. The next step is to create a standard which either allows the use of all instruments with a table defining the differences which can be used to convert readings between instruments or allows the use of only one instrument.

SECTION **3**

Project Results

3. PROJECT RESULTS

To keep the discussion within an established baseline, the ANSI Standard for determining surface texture method was used for dividing various instrumentation into two categories contacting and noncontacting. However, the ANSI Standard only specifies the requirements for one type of contacting instrument, i.e. , the Stylus type. The requirements for the other instrument types are specified by each manufacturer/supplier.

3.1 Contacting Methods

Contacting methods can be subdivided into four general types:

- Stylus
- Magnetic
- Replication
- Comparators

3.1.1 *Stylus Instruments*

Stylus instruments can be either electronic or manual. The electronic stylus instrument is very similar to a phonograph. A needle/stylus is drawn across the surface at a predetermined speed for a specific distance. The manual instrument consists of a platform which rests on the peaks and a stylus which is inserted into the valleys of the surface texture.

3.1.1.1 Electronic Stylus Instruments

As a minimum, the electronic stylus instrument consists of a stylus, stylus support, tracer head supports and indicating devices. The stylus tip radius is governed by specification and only a nominal 10 micrometer (400 microinch) effective (spherical) tip radius is allowed. The stylus is required to be cone-shaped with a nominally spherical tip; the standard stylus force cannot exceed 1.5 grams at any point within the displacement range of the stylus. Under normal operating conditions, the stylus support is not allowed to have any lateral deflections which may cause error. The

instrument sample length cutoff is variable but controlled by specification. The cutoff length corresponds to the length of the surface actually measured. The indicating device is required to read the arithmetic average (RA) in micrometers (microinches).

In addition to RA measurements, some instruments also read directly in Root Mean Square (Rq). Truly sophisticated instruments equipped with additional modules and/or minicomputers also print other factors such as:

- Maximum peak to valley in sample length (Rmax)
- Maximum depth below mean line
- Maximun height above mean line
- Peak Count (PC)
- Maximum peak to adjacent maximum valley

RA measurements are not truly descriptive measurements. For example, two totally different surface textures could have the same RA value. See Figure 3.1. Average roughness is the average height deviation of the profile from the mean line. As can be seen from the example, the RA value of the two simplified curves are the same even though peak count is different by a factor of 2.

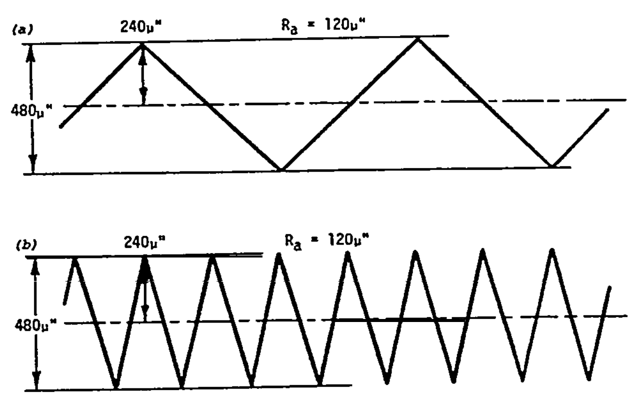


FIGURE 3.1: RA VALUES OF TWO DIFFERENT SURFACES

3.1.1.1.1 Description of Various Electronic Stylus Instruments

An example of a sophisticated electronic instrument is the Rank Precision Industries Talysurf 10 with Talydata VDU System.

This instrument meets all the requirements of ANSI B 46.1-1978 plus is equipped with a mini computer. The instrument package prints 23 parameters and a short profile graph of each reading (see Figure 3.2) and is capable of making up to five cutoff measurements simultaneously for each roughness assessment. The resulting printout presents data on each cutoff plus averaging data. For surface preparation roughness measurements, the cutoff length is generally 0.030 in. or 30 roils. With 5 cutoffs, this makes the actual measured length 5 X 0.030 or 0.150 in. For the purpose of this study, Rank Precision made and recorded ten roughness assessments for each surface preparation technique. The resulting data is presented in Section 4.

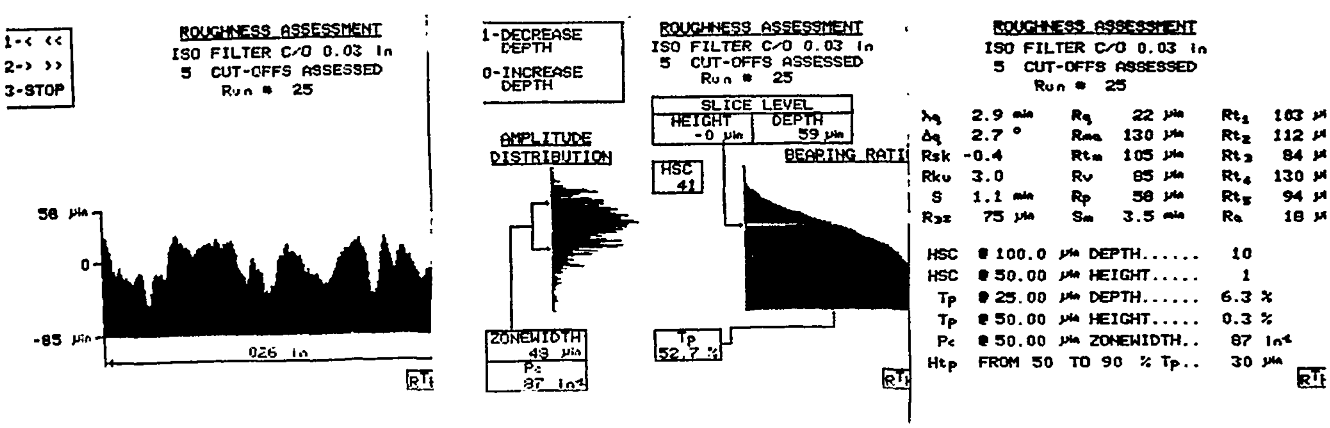
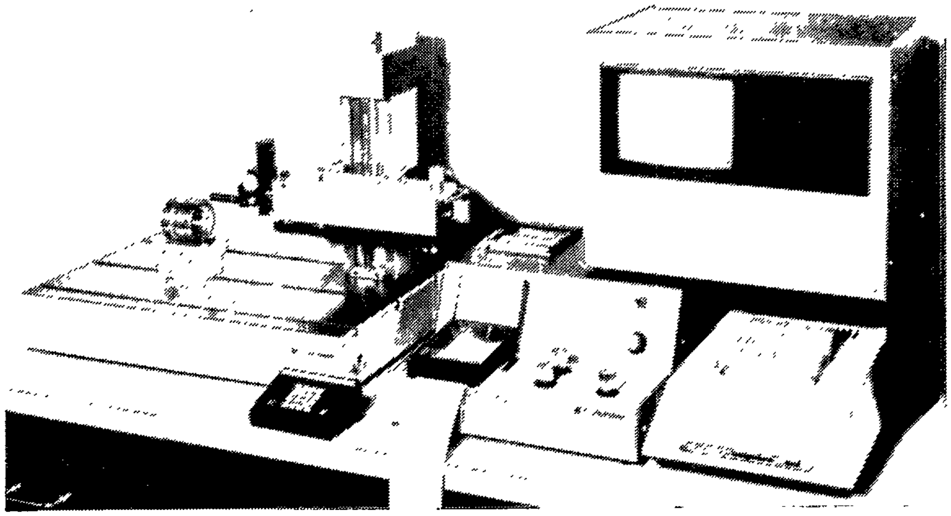


FIGURE 3.2: SAMPLE READOUT OF STYLUS INSTRUMENT

The instrument package is an ideal tool for further research on surface texture but is not suitable for routine shipyard measurements due to the size of the instrument and the necessity for electrical service and environmental control. (See Figure 3.3)



Talysurf 10MC-1S system with Talydata 1000-1 microcomputer and optional video printer.

FIGURE 3.3: SOPHISTICATED ELECTRONIC STYLUS INSTRUMENT

There are many, relatively rugged, portable stylus instrument packages. These instruments can measure surface roughness up to 1000 microinches. Some can only read up to 300 microinches. Normally only one measurment parameter, RA, can be measured even though sane instruments can be equipped with additional modules which can also measure Rq and PC. Listed below are some examples of these instruments. Also see Figure 3.4.

- Airtronics Metrosurf
- Alina Diavite Microtester
- Bendix Profilometer
- Harper Surfex
- Marduth Products Roughometer (used in Project)
- Rank Precision Surtronic 3

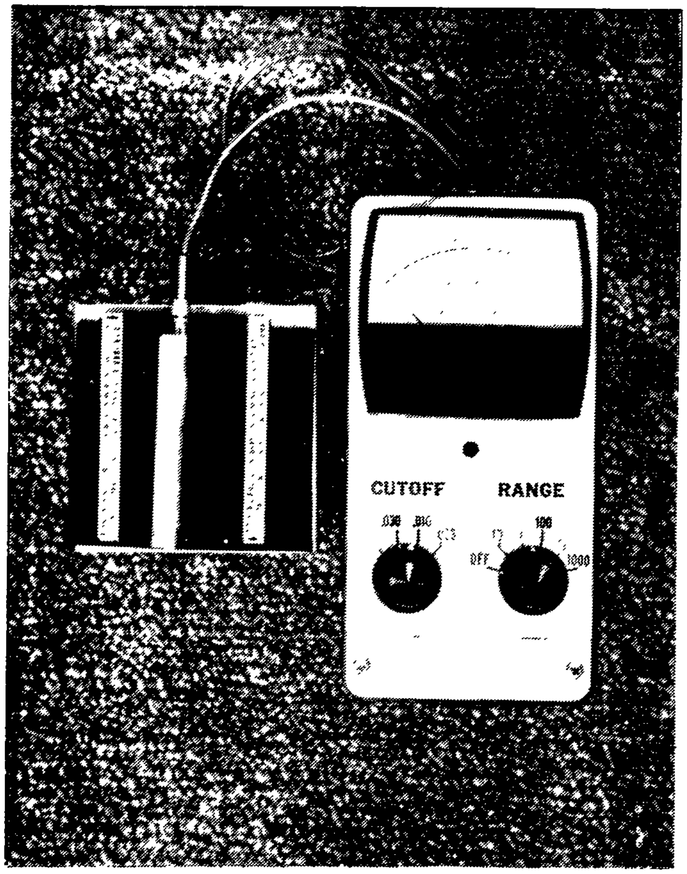


FIGURE 3.4: SMALL PORTABLE STYLUS INSTRUMENT

3.1.1.1.2 Advantages and Disadvantages of Electronic Stylus Instruments

A. Advantages

- Gives a number which requires no interpretation
- Some are portable
- Already established standard (ANSI B 46.1-1978)

- Numerous sources of manufacture
- Some units are light weight

B. Disadvantages

- Designed primarily for machine industry
- RA (& Rq) readings are not suitale for surface preparation measurements.
- Measurements of nondirectional surfaces (Normal Surface Prepared Surfaces) can vary by as much as 60%.
- Measurement results dependent on direction of lay and waviness
- Expensive ($1000 to $8000)
- Sensitivity to environment
- Requires operator skill
- Equipment setup is critical
- Stylus wears with use
- Stylus can alter the surface
- Stylus size can mask some roughness characteristics
- Built-in filtering circuit can mask some surface characteristics

3.1.1.2 Manual Stylus Instruments

As stated earlier, the manual stylus instrument consists of a platform which rests on top of the surface roughness peaks and a stylus which penetrates the valleys. The instrument is first zeroed by placing on a flat piece of glass. Twenty readings are made on the suface to be measured and then averaged. The average or mean is the profile height. In one instrument, the stylus is connected directly to a dial indicator which reads directly in roils, microns or micro-inches. In another instrument, the stylus is placed on the surface and the platform is adjusted until it just touches the top of the peaks. The platform is calibrated to measure the displacement distance via an adjustable scale. Still another adaptation of this principal uses thin sheets of paper, a micrometer and a platform with adjustable stylus. The platform stylus is first adjusted so that the stylus tip does notproytrude the platform. The platform is

then placed on the surface to be measured in such a manner that the platform rests on the peaks of the surface. while tightly holding the platform, the stylus is lowered into a surface texture valley and then locked into place. The platform with stylus protruding is then removed from the surface, place on a stack of thin paper, and drawn across the papers. The papers cut by the stylus are then restacked and the combined thickness measured with a micrometer. This number corresponds to the profile height. Even though not totally accurate, rough measurements can be made. Listted below are some of the suppliers of manual stylus instruments. (See Figure 3.5)

- Elcometer Instruments Ltd - Elcometer 123
- Zorelco - Wefting Micrometer

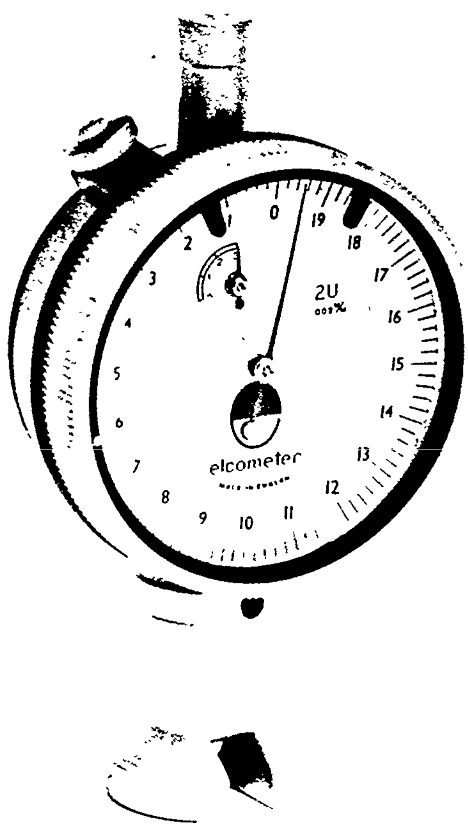


FIGURE 3.5: MANUAL STYLUS (Elcometer 123)

The advantages and disadvantages of the manual instruments are listed below:

A. Advantages

- Inexpensive ($300.00)
- Easy to use
- Minimum operator skill required
- Easy to carry, rugged construction, portable

B. Disadvantages

- Results Vary With Surface Lay
- Not Comparable Wiht Electronic Instruments - The size of the Base Which Rests on top of surface Texture is approximately 1 1/2″ in diameter whereas sampling length of the electronic instrument is 0.030″. Therefore, the manual instrument measures waviness plus roughness and the electronic instrument only measures roughness.
- Measured results vary with operator technique - Care must be exercised to place the instrument on the surface in such a manner that no movement is made once the stylus contacts the surface.

3.1.2 <u>Magnetic Instruments</u>

There are two types of magnetic instruments. One type, the magnetic snap-off gage, is based on the principle that the attractive force between a permanent magnet and a magnetic metal is inversely proportional to the distance between the masses. When the instrument is placed on the surface texture, a reading is given which is equal to the distance between the magnetic probe and a point which represents the average mass of the steel. The other type instrument, a magnetic induction gage, measures magnetic flux across an air gap which varies according to the proximity of the magnetic surface and the two contact points With are the poles of the

magnet. The scales on the instrument are calibrated to read directly in a profile height. (See Figure 3.6). A simple magnetic gauge normally used for measuring dry film thickness can be used if the operator has a conversion table to convert the average measured value to a profile value comparable to other measurement techniques.

Some available magnetic guages are listed below:

- Nordsen Mikrogage
- Elcometer Roughness Gage Model 101-45
- Electro-Physik Microtest Gage

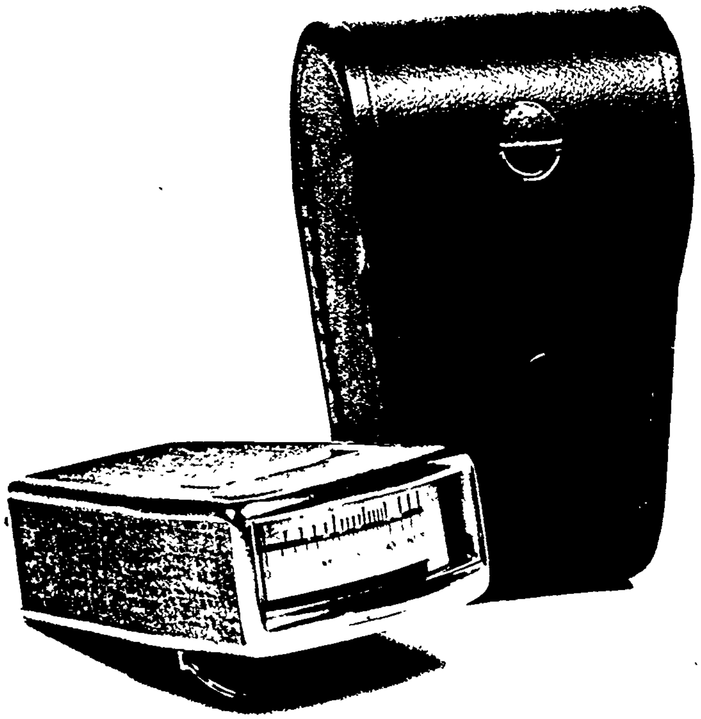


FIGURE 3.6: MAGNETIC PROFILE GAGE (Elcometer 101-45)

The advantages and disadvantages of magnetic guages are listed below:

A. Advantages

- Easy to carry, rugged construction, portable
- Easy to calibrate
- Gives a number which requires no interpretation
- No formal training required
- If used directly, without a conversion table or scale, the value measured equates to the minimum amount of measurable paint necessary to cover the profile.
- Inexpensive ($300.00).

B. Disadvantages

- Not directly comparable with electronic stylus instruments.
- Limited to magnetic substrates

3.1.3 Replication

There are two basic types of replication procedures. One involves the use of a replica tape which is placed on the surface to be measured and pressed or molded into the surface. The tape is then removed and transported to a laboratory where measurements are made from the replica using either microscopic, stylus or other techniques.

The second method consists of a procedure utilizing a specially prepared compsite replica tape (Testex Press-O-Film). The tape is first applied to the surface to be measured and rubbed with a burnishing tool to force the soft plastic part of the tape into the profile in such a manner that the peaks protrude through the soft plastic but not through the known thickness hard backing material. The resulting tape thickness is then equal to the profile plus that of the rigid backing material. A dial indicator which has been adjusted to allow for the thickness of the rigid backing material, is used to measure the profile height.

The advantages and disadvantages of the replication procedure are listed below:

A. Advantages

- Measurement results are consistent between operator
- Easy to carry, rugged construction, portable
- Easy to calibrate
- Gives a number which requires no interpretation
- No formal training required
- Inexpensive ($100.00)

B. Disadvantages

- Not directly comparable with electronic stylus instrument
- Size of area measured is approximately 1/4" and is therefore probably measuring part of surface waviness

3.1.4 Comparators

Comparators consists of surfaces which have been electrolytically reproduced from roughness standards. The surface to be measured is then compared to a series of different comparator standard surfaces either visually or by touch. The operator then selects the standard surface most representative of the surface being measured. The standard surface is labeled with an RA value or sane cede which represents the profile height. Of all the methods used, this is the most subjective.

Listed below are some of the suppliers of surface finish comparators:

- Flexbar Machine Corporation
- Gar Electroforming Division
- KTA Kenneth Tator Associates

The advantages and disadvantages of the comparator are discussed below:

A. Advantages

- l Easy to carry, rugged construction, portable
- l No calibration required
- l Inexpensive ($100.00)

B. Disadvantages

- • Subjective - Requires operator interpretation

3.1.5 Surface Volume Methods

This is another straight forward method. A very small known volume of non-evaporating oil (a drop), such as linseed oil, is is placed on the surface to be measured. A flat containment mechanism (plate glass) is placed over the oil and pressure exerted until the plate is in intimate contact with the surface. The diameter (d) of the area to which the oil spreads is then measured and recorded. Fran the known volume of the oil and the diameter of the neasured area wetted by the oil, the profile height (h) is expressed as:

$$h = \frac{\text{Volume}}{\pi \left(\frac{d}{2}\right)^2}$$

In another variation of this technique, a gas is used instead of oil. The amount of gas escaping around the containment plate is measured, and this reading is converted to surface volume. L. H. Tanner found that a “Pneumatic Wheatstone Bridge for Surface Roughness Measurements” yielded results comparable to those obtained from electronic stylus instruments.[9]

The advantages and disadvantages of the surface volume methods are listed below:

A. Advantages

- No calibration required
- Inexpensive ($100.00 or less)
- Easy to carry, portable

B. Disadvantages

- Not comparable with other methods
- Not repeatable
- Measures surface waviness and lay in addition to roughness
- Oil is source of paint contamination

3.1.6 Metallographic Sectioning

This is an old standard metallographic procedure. A sample is cut from the surface to be measured in a length and width convenient for laboratory handling, generally 0.75 inches by 0.75 inches. The sample is then cast in an epoxy, PVC or other mounting compound. Care must be exercised to insure that the sample is cast in such a manner as to facilitate accurate sectioning after the mounting compound has cured. A black or clear mounting compound is best to insure contrast between the sample end the mount. After curing, the sample is sectioned at either a 90 degree angle to the surface to be measured or to some other known angle. Following sectioning, the edge of the sample is hand polished on a flat surface using 120, 400 and then 600 grit wet/dry silicon carbide paper. The resulting sample is further polished using various grades of diamond pastes ending with the finest available.

After polishing, the sample is placed in a microscope where the profile can be observed and measured. If the sample has been sectioned at 90 degrees to the surface texture, the measurements can be made directly. Other angles can be used to magnify or reduce the actual profile. Besides

being a very tedious, labor consuming procedure, errors can be introduced which make the actual measurements erroneous. The angle of sectioning is extremely critical. AS stated earlier, any angle other than 90 degrees can magnify or reduce the profile. In addition, the surface texture has a tendency to smear during the polishing which shows up as a false roughness. The biggest drawback to this procedure is that it is destructive and requires metal repair of the area from which the sample is taken. Therefore, the procedure is not recommended for shipyards.

3.1.7 Grinding

Another destructive method of surface texture measurement consists of measuring the thickness of a sample using a micrometer. The surface texture is then removed with a grinder until no valleys are visible. The resulting thickness is remeasured and the difference is recorded as maximum peak-to-valley. Not only is this procedure destructive, but it is also not very accurate and has extremely poor repeatability.

3.1.8 Slip/Peel Testers

Even though not normally used to measure surface roughness as such, the slip/peel testers do measure surface coefficients of friction. With the proper development, the instrument could be adapted to measure surface roughness.

3.2 Noncontacting Methods

Noncontacting methods generally consist of either optical or electronic microscopic measurements; however, one instrument is available which uses light in a manner similar to a stylus instrument. Each type of procedure is discussed below.

3.2.1 Optical Instruments

3.2.1.1 Sentec Non-Contacting Surface Profiler

This instrument utilizes a patented optical technique which produces a stylus type profile measurement. A small spot of light is projected onto the test surface through an objective lens. The light spot is then reflected back through the lens and processed to accurately determine the distance between the objective lens and the spot of light on the surface. The measurement of the position of the spot on the surface gives a measurement of the height of the surface profile. Electronic filtering and signal processing are used to produce roughness and waviness readings. The unit is also equipped with a chart recorder. With the exception of stylus interference, the same disadvantages apply to this instrument package as applies to the electronic stylus instruments.

3.2.1.2 Two-beam Interferometry

This is a complicated process which uses both reflected and refracted light. The instrument can be adjusted to measure thin films and surface topography.

3.2.1.3 Light Section Microscope

The light section microscope is epuipped with a light source which is projected through a razor-thin slit diaphragm onto the surface to be measured and back into the objective lens of the microscope. The light source and the objective lens are positioned 90 degrees to each other and each forms a 45 degree angle with the surface being measured. Accurate measurements of surface roughness can be made by moving the reticle to observe the peaks and valleys of the profile.

The following companies supply light section microscopes:

- Nikon Incorporated
- Zeiss
- Elcometer (Roughtector Model 181)

3.2.1.4 Toolmaker Microscope

This is a method which is recommended by and written into the Steel Structures Painting Council (SSPC) specifications. it is a straightforward method for measuring profile height which uses a standard toolmakers microscope. This microscope is fitted with a calibrated measurement scale on the focus control. The microscope is first focused on the lowest point in the field of view and the location of the focus control recorded. The microscope is then focused on the highest point in the field of view and the location of the control noted. By subtracting the lower reading from the higher reading, the maximum profile displacement can be obtained. The roughness sampling length varies with the microscope used but generally ranges between 0.030 and 0.043 inches for 100X and is approximately 0.020 inches for 250X. The results should closely approximate maximum peak-to-valley measurements of the electronic stylus instrument with minicomputer; however, the results in section 4 do not support this conclusion.

This method is very tedious and tiring to the eye. It is not suitable for field use but can be combined with the replication method discussed in paragraph 3.1.3 to transport representative surface textures to the laboratory for measurement.

3.2.1.5 Advantages and Disadvantages of Optical Instruments

A. Advantages

- Can provide a true, measurable representation of surface texture

B. Disadvantages

- Requires laboratory environment
- Expensive
- Requires operator training
- Highly technical
- Not portable

3.2.2 Scanning Electron Microscopes (SEM)

The scanning electron microscope can be used two ways to analyze surface texture. As a standard microscope, the SEM provides excellent depth of field focus and presents an accurate picture of the actual surface. No readings of profile height can be taken directly from the surface; however, a micron marker can be added from which general measurements can be made. The second manner that the SEM can be used is very similar to the light section methods discussed in paragraph 3.2.1.4 except that electronic beams are used in lieu of light beams. Calpan has a patented process, SCRIMAGE, which provides quantitative profile measurements. Figure 3.7 provides an example of this process. Bausch and Lamb has a similar process which uses an "Image Analysis Instrument". This instrument can be adapted to measure roughness.

FIGURE 3.7: EXAMPLE OF SCRIMAGE PROCESS

3.2.3 Laser Technology

This is a new and promising technique; however, no working model could be found for evaluation. In this method, a laser beam could be used as an electronic stylus to measure surface texture. The results would he the same as those of the electronic stylus without sane of the pitfalls.

The electronic stylus will wear with use and give less accurate results with time whereas the laser beam does not the mechanical contact and therefore does not wear. This technology is available in such instruments as video and phonograph players.

SECTION 4
Laboratory Test Results

4. LABORATORY TEST RESULTS

4.1 scanning Electron Microscope (SEM)

Pages A-1 through A-14 maintain SEM photomicrographs of the various surface textures resulting from each surface preparation method. Each photograph was taken at l00X and 55 degree tilt to assure uniformity. As can be seen, excellent depth of field is presented. Pages A-6 and A-9 contain photomicrographs of visual comparator standards. The GS STD is for grit blast surfaces and the SH STD is for shot blasted surfaces. The number in parenthesis is the standard value for Roughness Average (RA).

4.2 Comparison of Various Measurement Results

4.2.1 Toolmaker/Replication/Stylus/Magnetic/surface Volume

Both 2" x 2" x 1/4" and 6" x 6" x 1/4" samples were prepared from new steel with intact mill scale.

The steel substrate average hardnesses were as follows:

A-36	74.78 Rockwell B
HY80	22.14 Rockwell C

The degree of cleaning when using abrasive blast techniques was "White Metal", SSPC 5. For pressure blast samples, the angle of attack was 90 degrees and the air pressure was 86 psig measured at the nozzle during blasting. The size nozzle used was 1/4" venturi. The centrifugal blasted samples were prepared in a production blast machine. Power tool cleaned surfaces were prepared in accordance with the Steel Structures Painting Council Power Tool Cleaning Specification, SSPC 3.

The magnetic snap-off gauge was calibrated to 1.5 roils using a National Bureau of Standards film thickness calibration standard. This standard consists of a non-magnetic film applied to a polished magnetic substrate.

The microscope method was accomplished at 100X with a field of vision diameter of approximately 0.030 inches.

The number of samples taken for each instrument were as follows :

- Toolmakers Microscope - 20
- Replication (Testex) - Generally 3 but sometimes 7
- Manual Stylus (Elcometer 123) - 20
- Electronic Stylus (Talysurf) - 50
- Electronic Stylus - Portable (Roughmeter) - 10
- Magnetic (microtest Gauge) - 20
- Surface Volume - 1

Tables I through V contain the results of the various measurement methods/ instruments obtained from the various surface textures.

Attempts at determining a precise mathematical relationship between the various measurement techniques were not successful. This was probably due to the random nature of cleaned surfaces. In many cases, the low/high values for some instruments actually overlapped. The range of the Toolmaker Microscope, Testex Replication procedure and Elcometer 123 readings were close enough to be considered within the same "Ball Park". In addition, the electronic stylus instrument has a filtering circuit which deletes some surface characteristics which could be a part of the profile. No method used was discerning enough to precisely measure differences when different abrasives were used for blasting. For example, the average values obtained when using the Testex method for LG-16, LG-25 and GL40 were 6.8, 4.6 and 5.0 roils respectively. Each of these abrasives is successively larger beginning with LG-16.

Another indication of the randomness of the measurements can be observed when comparing the magnitude of the Low/High sample spread and relationship between the average value (mean) and the standard deviation. In many cases, the coefficient of variation (standard deviation divided by mean) of these samples series varied by more than 30 per cent. As discussed

TABLE I

COMPARISON OF MEASUREMENT RESULTS - Abrasive Blast (A-36)

ABRASIVE		Toolmaker Microscope (MILS)	Replication Tape-Testex (MILS)	Manual Stylus Electrometer 123 (MILS)	Electronic Stylus w/minicomputer - Talysurf RM(MILS)**	PC	RA(Min)*	Electronic Stylus-Portable RA(Min)*	Magnetic Microtest (MILS)	Height Cal. from Surface Volume (MILS)
Air Blast	Average	6.1	3.3	4.0	2.2	30	386	943	0.6	
Steel Shot	Low/High	3.2/7.8	3.3/3.4	2.8/5.4	1.5/3.0	13/67	265/435	800/1000	0.2/0.9	5.5
S-280	STD. Dev.	1.06	0.6	0.8	0.416	15.99	48.64	76.42	0.21	
Air Blast	Average	4.7	3.2	3.3	2.2	22	391	925	0.6	
Steel Shot	Low/High	1.5/7.5	3.0/3.4	2/5	1.5/2.6	13/27	295/440	850/1000	0.3/1.1	13.2
S-330	STD. Dev.	1.28	0.2	0.84	0.37	4.72	41.46	75.46	0.20	
Air Blast	Average	5.3	3.3	4.7	2.5	29	388	965	0.8	
Steel Shot	Low/High	3.5/7.1	3.2/3.4	3.7/5.6	1.7/3/7	20/40	325/455	850/1000	0.3/1.8	3.7
S-390	STD. Dev.	1.0	0.12	0.61	0.65	6.55	45.55	52.97	0.43	
Centrifugal	Average	4.6	3.1	4.2	2.6	28	415	1000+	0.6	
Blast	Low/High	3.3/6.5	3.1/3.2	2.6/5.7	2.0/3.4	20/40	355/555	--	.2/1.1	7.4
Oper. Mix	STD. Dev.	1.0	0.06	0.82	0.39	6.78	60.05	--	0.23	
Air Blast	Average	6.8	4.2	7.7	3.9	30	615	1000+	1.2	
Steel Grit	Low/High	4.2/12.2	3.7/4.8	4.2/10.0	3.3/4.5	20/40	510/660	--	0.4/2.4	8.4
LG-16	STD. Dev.	1.99	0.57	1.5	0.47	7.10	43.78	--	0.57	
Air Blast	Average	4.6	3.8	8.1	3.4	28	544	1000+	1.1	
Steel Grit	Low/High	2.7/6.9	3.8/3.9	5.6/10.5	2.3/4.3	20/40	415/670	--	0.4/1.8	12.5
LG-25	STD. Dev.	1.16	0.06	1.45	0.59	7.46	75.42	--	0.38	
Air Blast	Average	5.0	3.8	4.7				873	0.7	Not
Steel Grit	Low/High	2.0/6.5	3.7/4.0	2.7/7.8				750/1000	0.4/1.0	Measured
GL-40	STD. Dev.	1.02	0.15	1.13				75.87	0.19	
Air Blast	Average	4.5	3.0	4.0	2.5	38	413	878	0.7	
Steel Grit	Low/High	3.0/6.7	2.9/3.1	3.0/5.0	2.2/2.9	27/67	345/495	755/1000	0.3/1.0	3.7
GP-40	STD. Dev.	0.91	0.09	0.65	0.24	11.53	38.02	81.18	0.23	
Air Blast	Average	4.2	2.9	3.8	2.1	24	340	1000+	0.6	
ASTM	Low/High	1.1/6.2	2.6/3.4	2.4/5.7	1.6/2.4	13/33	290/395	--	0.2/0.9	9.1
Sand	STD. Dev.	1.30	0.42	0.79	0.27	7.24	32.40	--	0.18	

*Microinch
**RM=Rmax

TABLE I (contd)

COMPARISON OF MEASUREMENT RESULTS - Abrasive Blast (A-36)

ABRASIVE		Toolmaker Microscope (MILS)	Replication Tape-Testex (MILS)	Manual Stylus Electrometer 123 (MILS)	Electronic Stylus w/minicomputer - Talysurf RM(MILS)**	PC	RA/Min)*	Electronic Stylus-Portable RA(Min)*	Magnetic Microtest (MILS)	Height Cal. from Surface Volume (MILS)
Air Blast	Average	3.8	2.9	3.5				898	0.7	
20-30 Mesh	Low/High	0.6/5.7	2.8/3.1	2.2/5.3				750/1000	0.4/1.1	10.7
Sand	STD. Dev.	1.35	0.14	0.73				83.71	0.21	
Air Blast	Average	4.0	2.9	4.2	2.8	35	467	853	0.8	
Parker Bros.	Low/High	1.8/5.7	2.6/3.1	2.5/5.2	2.3/3.5	20/53	365/600	650/950	0.5/1.8	7.8
Mineral Grit	STD. Dev.	1.06	0.19	0.78	0.35	10.85	76.89	96.07	0.34	
Air Blast	Average	3.7	2.8	3.3	1.6	42	237	918	0.4	
Star Blast	Low/High	1.3/5.8	2.3/3.4	1.5/4.9	1.2/2.0	20/73	215/285	775/1000	0.3/0.7	3.4
Mineral Grit	STD. Dev.	1.29	0.48	1.02	0.23	16.42	25.40	89.79	1.0	
Air Blast	Average	4.7	3.1	4.9	2.7	33	399	1000+	0.8	
Saf-T-Blast	Low/High	2.7/6.2	3.0/3.3	2.8/7.0	2.2/3.5	27/60	310/505	--	0.5/1.4	7.7
Coal Slag	STD. Dev.	1.0	0.12	0.98	0.43	12.55	57.15	--	0.24	
Air Blast	Average	4.5	3.3	4.6	2.6	33	395	1000+	1.0	
Stan Blast	Low/High	1.9/7.3	2.7/4.4	2.8/7.5	2.0/3.3	13/53	330/505	--	0.5/1.8	6.0
Coal Slag	STD. Dev.	1.31	0.59	1.27	0.38	14.61	50.16	--	0.35	

*Microinch

**RM=Rmax

TABLE II

COMPARISON OF MEASUREMENT RESULTS - Abrasive Blast (HY80 Steel)

ABRASIVE		Toolmaker Microscope (MILS)	Replication Tape-Testex (MILS)	Manual Stylus Electrometer 123 (MILS)	Electronic Stylus w/minicomputer - Talysurf RM(MILS)**	PC	RA(Min)*	Electronic Stylus-Portable RA(Min)*	Magnetic Microtest (MILS)	Height Cal. from Surface Volume (MILS)
Air Blast	Average	4.9	2.6	3.0	2.0	30	342	740	0.7	
Steel Shot	Low/High	3.1/8.4	2.6/2.7	2/4.8	1.6/3.2	20/40	270/420	650/850	0.4/1.1	5.7
S-280	STD. Dev.	1.15	0.06	0.81	0.49	6.3	54	65.8	0.18	
Air Blast	Average	5.8	3.0	3.2				825	0.6	
Sheet Shot	Low/High	4.3/7.7	2.8/3.1	2.0/4.6				750/1000	0.3/1.0	13.2
S-330	STD. Dev.	0.98	0.13	0.69				92	0.20	
Air Blast	Average	5.3	3.1	3.7				823	0.7	
Steel Shot	Low/High	2.8/7.9	3.0/3.4	2.1/5.2				725/950	0.3/1.4	4.1
S-390	STD. Dev.	1.28	0.23	0.98				85.4	0.21	
Centrifugal	Average	5.1	2.4	3.1	2.1	27	351	650	0.6	
Blast-Steel	Low/High	3.3/7.6	2.4/2.5	2.0/4.7	1.6/2.6	20/40	315/420	550/750	0.3/1.1	3.9
Oper. Mix	STD. Dev.	1.06	0.05	0.72	0.33	6.55	33	68.7	0.22	
Air Blast	Average	6.1	4.2	6.6	3.6	29	571	1000+	1.1	
Steel Grit	Low/High	4.3/8.5	3.8/4.9	1.5/10.1	3.1/4.4	20/40	420/700	--	0.4/2.5	6.9
LG-16	STD. Dev.	1.07	0.59	1.95	0.52	8.28	97.9	--	0.55	
Air Blast	Average	3.7	3.7	6.4	3.8	34	559	1000+	1.1	
Steel Grit	Low/High	3.4/4.2	3.4/4.2	4.6/9.0	2.7/5.0	20/50	480/700	--	0.5/2.1	8.7
LG-25	STD. Dev.	0.436	0.44	1.429	0.8	12.0	99.9	--	0.4	
Air Blast	Average	4.7	2.7	4.3	2.5		366	883	0.96	Not
Steel Grit	Low/High	2.1/6.8	2.7/2.8	1.8/6.2	1.7/3.3		290/580	750/950	0.5/1.6	Measured
GL-40	STD. Dev.	1.15	0.06	1.0	0.47		74.98	68.77	0.34	
Air Blast	Average	3.8	2.7	3.4				781	0.65	
Steel Grit	Low/High	2.4/5.1	2.5/3.1	2.4/6.0				600/925	0.3/1.0	5.5
GP-40	STD. Dev.	0.69	0.32	1.03				104	0.22	
Air Blast	Average	3.9	2.6	3.1				765	0.65	
ASTM	Low/High	2.1/4.8	2.5/2.7	1.8/4.2				650/850	0.3/1.0	4.6
Sand	STD. Dev.	0.81	0.1	0.71				67.9	0.20	

*Microinch
**RM=Rmax

TABLE II (contd)

COMPARISON OF MEASUREMENT RESULTS - Abrasive Blast (HY80 Steel)

ABRASIVE		Toolmaker Microscope (MILS)	Replication Tape-Testex (MILS)	Manual Stylus Electrometer 123 (MILS)	Electronic Stylus w/minicomputer - Talysurf RM(MILS)**	PC	RA(Min)*	Electronic Stylus-Portable RA(Min)*	Magnetic Microtest (MILS)	Height Cal. from Surface Volume (MILS)
Air Blast	Average	5.1	2.6	2.9	1.8	32	313	780	0.6	
20-30	Low/High	3.6/6.3	2.5/2.8	1.4/4.1	1.6/2.0	13/47	255/400	725/850	0.4/1.0	3.3
Sand	STD. Dev.	0.73	0.12	0.73	0.17	1.7	45.4	36.9	0.18	
Air Blast	Average	3.1	2.7	3.3	2.2	45	305	765	0.9	
Parker Bros.	Low/High	0.8/4.6	2.5/2.8	1.0/5.2	1.5/3.3	20/60	255/355	650/850	0.5/1.4	3.7
Mineral Grit	STD. Dev.	1.1	0.14	0.93	0.52	14	30.04	61.46	0.22	
Air Blast	Average	2.6	2.2	2.5				578	0.5	
Star Blast	Low/High	1.7/3.8	2.0/2.4	1.4/4.0				450/900	0.2/0.8	7.5
Mineral Grit	STD. Dev.	0.54	0.17	0.7				149.7	0.20	
Air Blast	Average	4.4	2.5	2.9	1.8	44	280	690	0.7	
Saf-T-Blast	Low/High	1.6/6.1	2.2/2.8	1.5/4.7	1.4/2.5	20/73	230/330	625/825	0.4/0.9	3.5
Cool Slag	STD. Dev.	1.11	0.22	0.78	0.30	14.3	28.7	61.5	0.19	

*Microinch
**RM=Rmax

TABLE III

COMPARISON OF MEASUREMENT RESULTS - Power Tool (A-36)

TECHNIQUE		Replication Tape-Testex (MILS)	Manual Stylus Electrometer 123 (MILS)	Electronic Stylus w/minicomputer - Talysurf RM(MILS)**	PC	RA(Min)*	Electronic Stylus - Portable RA(Min) *	Magnetic Microtest (MILS)	Height Cal. from Surface Volume (MILS)
Disc Grind Rusted Panel	Average	1.6	1.1	1.1	20	128	338	0.4	
	Low/High	1.2/2.0	0.6/1.8	.6/1.9	7/53	70/175	250/400	.1/1.0	1.9
	STD. Dev.	0.31	0.35	0.42	13.63	33.02	43.30	0.27	
Disc Grind Primed & Rusted	Average	1.4	1.5	0.3	25	36	327	0.2	
	Low/High	1.1/1.7	0.3/2.5	0.2/0.6	7/67	20/59	250/400	0.1/0.3	5.6
	STD. Dev.	0.30	0.54	0.11	17.7	11.19	55.86	0.08	
Needle Gun Rusted Panel	Average	1.8	2.2	1.0	2 2	168	550	0.4	
	Low/High	1.6/2.0	0.9/5.2	.7/1.5	13/27	130/205	450/700	0.2/0.8	3.5
	STD. Dev.	0.21	1.39	0.31	7.24	28.6	89.82	0.16	
Needle Gun Primed & Rusted	Average	1.6	1.5	1.2	18	184	550	0.4	
	Low/High	1.3/2.0	0.7/2.2	0.7/1.5	13/27	120/230	550/625	0.2/1.0	2.9
	STD. Dev.	0.28	0.44	0.30	4.67	34.70	55.39	0.19	
Wire Wheel Rusted Panel	Average	1.9	1.8				508	0.4	
	Low/High	1.5/2.1	0.7/4.1				400/650	0.1/0.9	2.1
	STD. Dev.	0.29	0.79				74.1	0.23	
Wire Wheel Primed & Rusted	Average	1.6	1.6	1.0	23	191	369	0.2	
	Low/High	1.0/1.8	0.6/2.5	0.7/1.6	13/33	125/235	225/500	0.1/0.2	8.0
	STD. Dev.	0.25	0.59	0.28	7.97	34.38	86.90	0.20	
Flap Rusted Panel	Average			0.5	25	72			Not Measured
	Low/High			0.3/0.6	20/40	50/90			
	STD. Dev.			0.82	6.37	12.74			
Flap Primed & Rusted	Average	1.6	1.9	0.5	29	73	352	0.1	
	Low/High	1.4/1.8	1.0/3.2	0.3/0.8	13/47	55/100	200/450	0.1/0.2	8.3
	STD. Dev.	0.16	0.55	0.14	10.61	13.98	89.48	0.04	

*Microinch
**RM=Rmax

TABLE IV

COMPARISON OF MEASUREMENT RESULTS - Power Tool (HY80)

TECHNIQUE		Replication Tape-Testex (MILS)	Manual Stylus Electrometer 123 (MILS)	Electronic Stylus w/minicomputer - Talysurf RM(MILS)**	PC	RA(Min)*	Electronic Stylus - Portable RA(Min)*	Magnetic Microtest (MILS)	Height Cal. from Surface Volume (MILS)
Disc Grind	Average	1.2	1.2	0.6	12	64	267	0.3	
Rusted Panel	Low/High	1.0/1.4	0.3/2.1	0.4/1.0	7/20	45/100	225/350	0.1/0.6	3.2
	STD Dev.	0.19	0.63	0.22	5.95	19.69	50.38	0.11	
Disc Grind	Average	1.3	1.0	0.3	30	43	198	0.1	
Primed &	Low/High	1.2/1.4	0.1/3.4	0.2/0.6	13/53	25/58	150/300	0.1/0.3	2.7
Rusted Panel	STD Dev.	0.06	0.87	0.13	12.68	11.29	41.91	0.06	
Needle Gun	Average	2.1	3.2	0.8	19	125	656	0.6	
Rusted	Low/High	1.8/2.3	2.0/4.9	0.6/0.9	7/33	95/160	550/850	0.3/1.1	6.3
Panel	STD Dev.	0.23	0.78	0.11	8.84	19.44	97.77	0.23	
Needle Gun	Average	1.7	2.0				458	0.5	
Primed &	Low/High	1.2/2.2	0.5/4.0				350/550	0.2/1.0	3.5
Rusted	STD Dev.	0.43	0.76				70.17	0.25	
Wire Wheel	Average	1.5	1.6	0.5	18	87	269	0.3	
Rusted	Low/High	1.2/1.8	0.7/2.8	0.3/1.0	7/27	55/125	250/350	0.1/0.7	5.9
Panel	STD Dev.	0.25	0.53	0.21	7.06	17.33	33.92	0.15	
Wire Wheel	Average	1.8	2.3	0.6	17	106	471	0.4	
Primed &	Low/High	1.4/2.2	1.2/3.5	0.4/0.7	13/27	75/130	375/600	0.1/1.1	5.2
Rusted	STD Dev.	0.30	0.63	0.96	5.12	19.41	71.38	0.23	
Flap	Average			0.7	75	90			Not
Rusted	Low/High			0.5/0.9	40/113	75/105			Measured
Panel	STD Dev.			0.11	23.58	10.0			
Flap	Average	1.3	1.5	0.6	65	78	292	0.1	
Primed &	Low/High	1.0/1.5	0.6/2.8	0.5/0.8	20/108	65/100	225/400	0.1/0.2	2.7
Rusted	STD Dev.	0.19	0.60	0.11	35.43	10.85	54.70	0.03	

*Microinch
**RM=Rmax

TABLE V

COMPARISON OF MEASUREMENT RESULTS - Pickled Steel

Substrate		Replication Tape-Testex (MILS)	Manual Stylus Electrometer 123 (MILS)	Electronic Stylus w/minicomputer - Talysurf RM(MILS)**	PC	RA/Min)*	Electronic Stylus - Portable RA(Min)*	Magnetic Microtest (MILS)	Height Cal. from Surface Volume (MILS)
A-36	Average	2.7	3.0	1.7	36	252	1000+	0.4	3.4
	Low/High	2.2/3.1	0.9/4.5	1.3/2.5	13/67	230/325	--	0.2/0.7	
	STD. Dev.	0.31	0.93	0.36	19.26	33.5	--	0.13	
HY80	Average	2.7	2.1	2.0	31	243	679	0.2	2.6
	Low/High	2.5/2.8	1.2/3.7	1.7/2.6	7/60	200/285	600/800	0.1/0.3	
	STD. Dev.	0.10	0.78	0.33	16.16	30.21	49.81	0.07	

*Microinch
**RM=Rmax

earlier, one major reason for the differences in measurement results is differences of sample length.

NACE Task Group T-GG-19, "Field Measurement of Surface Profiles on Metal.", conductd round-robbin profile measurements on 14 different panels (7 different dbrasives and 2 degrees of cleaning) by 7 different observers. The measurement techniques include Elcometer 123, Testex tape and Keane-Tator comparator. This study group found that the Textex method gave closest correlation to the optical microscope and that the must promising candidate methods were the Elcometer 123 and Testex. The group also found that, with the exception of Testex, the statistical average of all the methods showed a significant variation.

The surface volume technique seemed to give totally random measurements. Part of the problem was the inability to make numerous measurements on each sample and the large size of the sample length.

4.2.2 Visual Comparators.

Tables VI and VII contain the results of visual comparisons. Again no clear-cut relationship could be established. As stated earlier, this is a totally subjective evaluation. The observer views the surface to be compared under magnification and then makes a comparison with a standard surface.

The visual comparators could not be used for power tool cleaned surfaces unless oriented to the proper light direction and only then for isolated areas and not the entire surface.

Table VIII is a recapitulation of the results obtained by three different trained observers. In only one case out of 14 observations did all three observers select the same standard. In some cases all three observers picked different standards. The arbitrary nature of this procedure makes it totally unsatisfactory.

TABLE VI - COMPARISON OF THE AVERAGE MEASURED

VALUES (MILS) OF VARIOUS INSTRUMENTS TO KEANE-TATOR VISUAL COMPARATOR

Sample Prep	Steel Type	Toolmaker Microscope	Replica Testex	Man. Stylus Electrometer 123	Elec. Stylus Talysurf	Magnetic Mircrotest	Surface Volume	Keane-Tator Comparator
A.B. S-280	A-36	6.1	3.3	4.0	2.2	0.6	5.5	3.0
A.B. S-280	HY80	4.9	2.6	3.0	2.0	0.7	5.7	3.0
A.B. S-330	A-36	4.7	3.2	3.3	2.2	0.6	13.2	5.5
A.B. S-330	HY80	5.8	3.0	3.2		0.6	13.2	4.0
A.B. S-390	A-36	5.3	3.3	4.7	2.5	0.8	3.7	5.5
A.B. S-390	HY80	5.3	3.1	3.7		0.7	4.1	4.0
Cent. Blast	A-36	4.6	3.1	4.2	2.6	0.6	7.4	3.0
Cent. Blast	HY80	5.1	2.4	3.1	2.1	0.6	3.9	2.5
A.B. LG16	A-36	6.8	4.2	7.7	3.9	1.2	8.4	4.5
A.B. LG16	HY80	6.1	4.2	6.6	3.6	1.1	6.9	4.5
A.B. LG25	A-36	4.6	3.8	8.1	3.4	1.1	12.5	5.5
A.B. LG25	HY80	3.7	3.7	6.4	3.8	1.1	8.7	4.5
A.B. GL40	A-36	5.0	3.8	4.7		0.7		4.5
A.B. GL40	HY80	4.7	2.7	4.3	2.5	0.96		3.0
A.B. GP40	A-36	4.5	3.0	4.0	2.5	0.7	3.7	2.0
A.B. GP40	HY80	3.8	2.7	3.4		0.65	5.5	2.0
A.B. ASTMSand	A-36	4.2	2.9	3.8	2.1	0.6	9.1	4.5
A.B. ASTMSand	HY80	3.9	2.6	3.1		0.65	4.6	3.0

TABLE VI - COMPARISON OF THE AVERAGE MEASURED

VALUES (MILS) OF VARIOUS INSTRUMENTS TO KEANE-TATOR VISUAL COMPARATOR (contd)

Sample Prep	Steel Type	Toolmaker Microscope	Replica Testex	Man. Stylus Electrometer 123	Elec. Stylus Talysurf	Magnetic Microtest	Surface Volume	Keane-Tator Comparator
A.B. 20-30 Sand	A-36	3.8	2.9	3.5		0.7	10.7	3.0
A.B. 20-30 Sand	HY80	5.1	2.6	2.9	1.8	0.6	3.3	2.0
A.B. Min. Grit	A-36	4.0	2.9	4.2	2.8	0.8	7.8	3.0
A.B. Min. Grit	HY80	3.1	2.7	3.3	2.2	0.9	3.7	2.0
A.B. Starblast	A-36	3.7	2.8	3.3	1.6	0.4	3.4	3.0
A.B. Starblast	HY80	2.6	2.2	2.5		0.5	7.5	1.5
A.B. Saf-T-Blast	A-36	4.7	3.1	4.9	2.7	0.8	7.7	2.0
A.B. Saf-T-Blast	HY80	4.4	2.5	2.9	1.8	0.7	3.5	3.0
A.B. STAN Blast	A-36	4.5	3.3	4.6	2.6	1.0	6.0	3.0

TABLE VII

COMPARISON OF THE AVERAGE TALYSURF AND PORTABLE STYLUS MEASUREMENTS (RA)
TO
GAR VISUAL COMPARATOR

(Al1 measurements are microinches)

Sample Prep	Talysurf Stylus	Portable Stylus	GAR Standard
S-280	386	943	500
S-330	391	925	1000
S-390	388	965	500
Cent Opr. Mix	415	1000+	500
LG16	615	1000+	1000
LG25	544	1000+	1000
GP40	413	878	500
ASTM Sand	340	1000+	500
Pkr Bros Min. Grit	467	853	500
Star Blast	237	918	500
SAF-T-Blast	399	1000+	500
STAN Blast	395	1000+	1000

TABLE VIII

VISUAL COMPARATOR (KT) RESULTS - THREE OBSERVERS

Abrasive Used	Observer #1	Observer #2	Observer #3
S-280	3.0 SH 76	4.0 SH 76	3.0 SH 76
S-330	5.5 SH 76	5.5 SH 76	4.0 SH 76
S-390	3.0 SH 76	5.5 SH 76	5.5 SH 76
Cent. Opr. Mix	3.0 SH 76	2.5 SH 76	4.0 SH 76
LG-16	4.5 G/S 76	4.5 G/S 76	5.5 G/S 76
LG-25	4.5 G/S 76	5.5 G/S 76	5.5 G/S 76
GL-40	3.0 G/S 76	4.5 G/S 76	4.5 G/S 76
GP-40	2.0 G/S 76	2.0 G/S 76	3.0 G/S 76
ASTM Sand	4.5 G/S 76	3.0 G/S 76	4.5 G/S 76
20-30 Sand	3.0 G/S 76	3.0 G/S 76	3.0 G/S 76
Parker Bros - Mineral Grit	3.0 G/S 76	2.0 G/S 76	3.0 G/S 76
Starblast - Mineral Grit	3.0 G/S 76	5.5 G/S 76	3.0 G/S 76
Saf-T-Blast - Coal Slag	3.0 G/S 76	1.5 G/S 76	3.0 GIS 76
Stan Blast - Coal Slag	4.5 G/S 76	3.0 G/S 76	3.0 G/S 76

4.2.3 Microsectioning

Table IX contains the results of microsectioning measurements using selected samples.

TABLE IX

Microsection Measurements

Abrasive		Microsection (Mils)	Toolmakers Microscope (Mils)
S-330	Average	1.5	4.7
	Low/High	0.4/3.0	1.5/7.5
	Std. Dev.	0.65	1.28
GL40	Average	1.3	4.7
	Low/High	0.1/3.4	2.1/6.8
	Std. Dev.	0.89	1.15

These measurements do not equate to any of the other techniques. Since the measurements were made with the same instrument, the Toolmaker microscope readings should be similar but are not. Figures 4.1 and 4.2 are photomicrographs of the sectional surfaces.

FIGURE 4.1: MICROSECTION OF S-330 ABRASIVE BLASTED SURFACE (100X)

FIGURE 4.2: MICROSECTION OF G40 ABRASIVE BLASTED SURFACE (100X)

4.3 Adhesion Test Results

In addition to the measurements made with the various surface texture instruments, an attempt was also made to euquate surface texture to relative adhesion. The Elcometer Button Adhesion Test was used. In this procedure a button is glued to the surface and then removed by a measured tensil force. Table X gives the results of these tests.

These test results reveal no major adhesion value differences as related to abrasive blasted surfaces regardless of the surface texture (profile) height. However, there is a dramatic difference between abrasive blasted surfaces and power tool cleaned surfaces. This difference is probably due to the contamination which remains on the surface after cleaning (see Figure 4.4). The button in the upper left comer was removed from a rusted panel cleaned with a power wire wheel. The lower left corner button was removed from a panel cleaned by abrasive blasting with GP40 steel. grit. The upper right and lower right buttons were removed from flap and needle gun cleaned surface respectively.

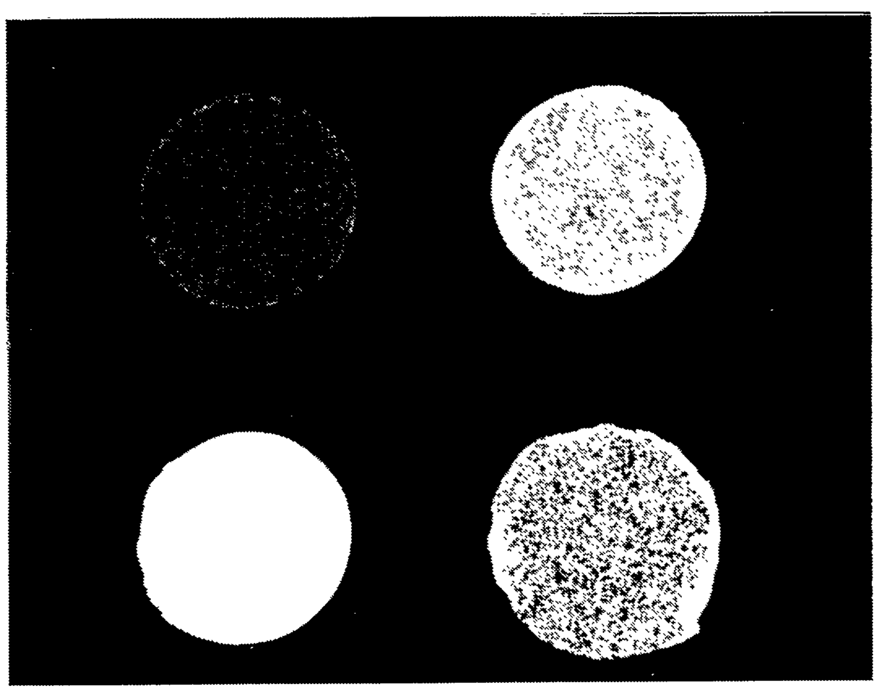


FIGURE 4.3: ADHESION TEST BUTTON SHOWING CONTAMINATION

Table X

Adhesion Test Results

Substrate Preparation	Adhesion Values (Average psi)
S-280	3000
S-330	2300
S-390	2300
Centrifugal Blast	2500
LG 16	1700
GP 40	2700
Starblast	3300
Disc Grid - Rusted Panel	900
Disc Primed/Rusted Panel	1200
Needle Gum - Rusted Panel	1200
Needle Gun - Primed/Rusted Panel	1100
WireWheel - Rusted Panel	1000
Wirewheel - Primed/Rusted panel	1000
Flap - Primed/Rusted Panel	1200

4.4 Paint Performance

A search was made through test data available from other testing programs to determine if a relationship could be drawn between the type of abrasive used to clean the substrate and resulting performance.

Figures 4.4 and 4.5 are photographs of an inorganic zinc paint system Which was applied over four test panels, each cleaned to "White Metal" with a different abrasive. The abrasives used from left to right are GL 40 steel grit, starblast, coal slag, and sand. The panels in Figure 4.5 were exposed on an exterior test fence at 45 degree south in Jacksonville, Florida, for five years in a marine environment. The panels in Figure 4.6 were first exposed for sixty days on an exterior test fence and then to a salt fog in accordance with ASTM B117 for 6000 hours. In all cases the inorganic zinc performed the same - no corrosion. From these test results, no difference in performance could be detected.

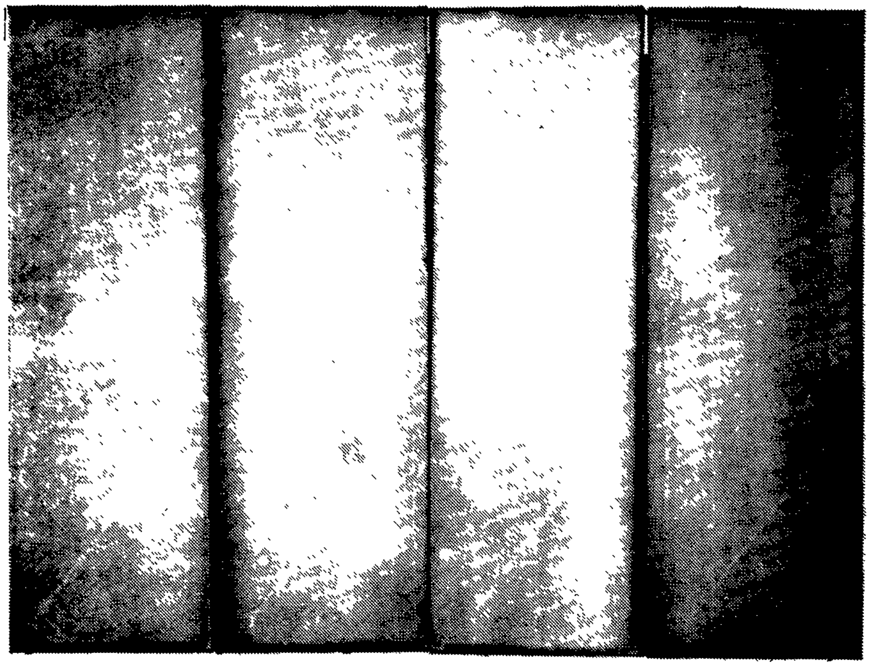


FIGURE 4.4: FIVE YEAR EXTERIOR TEST FENCE RESULTS (45° SOUTH IN A MARINE ENVIRONMENT) OF INORGANIC ZINC APPLIED TO FOUR DIFFERENT BLAST MEDIA PREPARED SURFACES

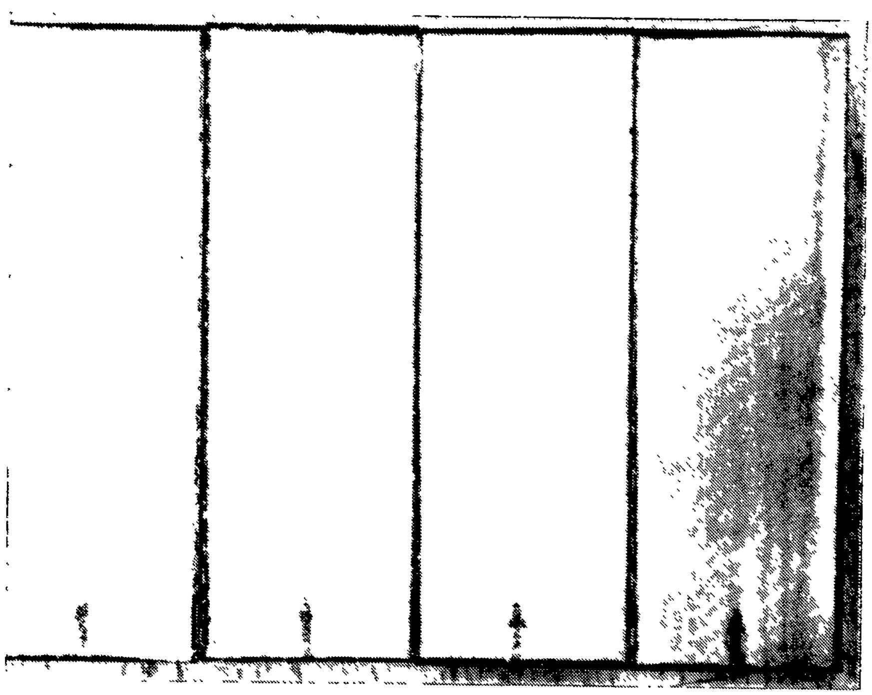


FIGURE 4.5: 6000 HOUR SALT FOG TEST RESULTS (ASTM B 117) OF INORGANIC ZINC APPLIED TO FOUR DIFFERENT BLAST MEDIA PREPARED SURFACES

SECTION 5
Summary

5. SUMMARY

In Sections 2 and 3 of this report, discussions have been offered which define surface texture characteristics and critique methods and procedures for measuring these characteristics. section 4 has summarized test data.

The most important definitions are surface texture, lay, waviness, roughness, profile, measured profile, peak, valley, roughness average (RA), peak-to-valley height, peak count, and sampling length. Each of these definitions have a definite relationship to one another. When discussing and measuring surf ace texture, these relationships must be remembered.

In surface preparation for painting, the terms profile or anchor pattern are widely used. As defined earlier in this report, profile is the contour of the surface in a plane perpendicular to the surface. No reference is made to sampling length. Sampling length is all important and determines whether or not lay and/or waviness are included within the measurement extremes. The various instruments discussed in this report have varying sample lengths from 0.030 inch to 1-1/2 inches. This explains sane of the wide deviations in measurement results.

The primary concern is to establish a standard method of defining surface texture. Measurement terms should be exactly defined. Instrument components must also be specified as to dimensions, sampling length and calibration.

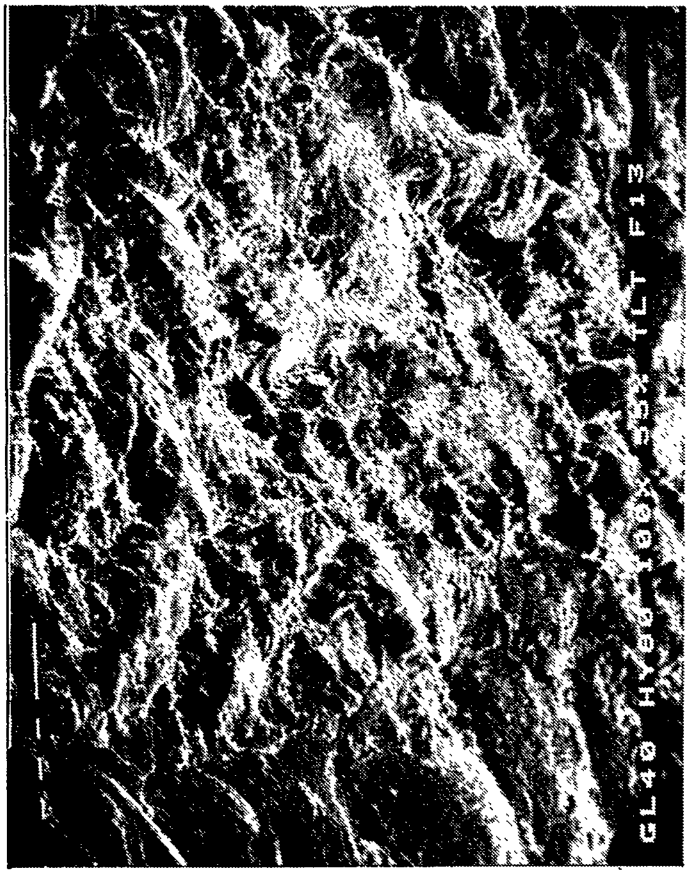
Of the instruments and procedures investigated and tested, the Elcometer 123 Profilometer, the Testex Replicate Method, and the snap-off magnetic gages are the easiest to use. Even though the measurements made are not directly comparable between instruments, a rough relationship exists between instruments which is representative of a maximum peak-to-valley measurement within a given sampling length. Depending on the instrument, this sampling length could include lay, waviness or roughness. Since paint adheres on a micro level and has a tendency to follow the major contours (waviness and lay), the most important measurement is roughness.

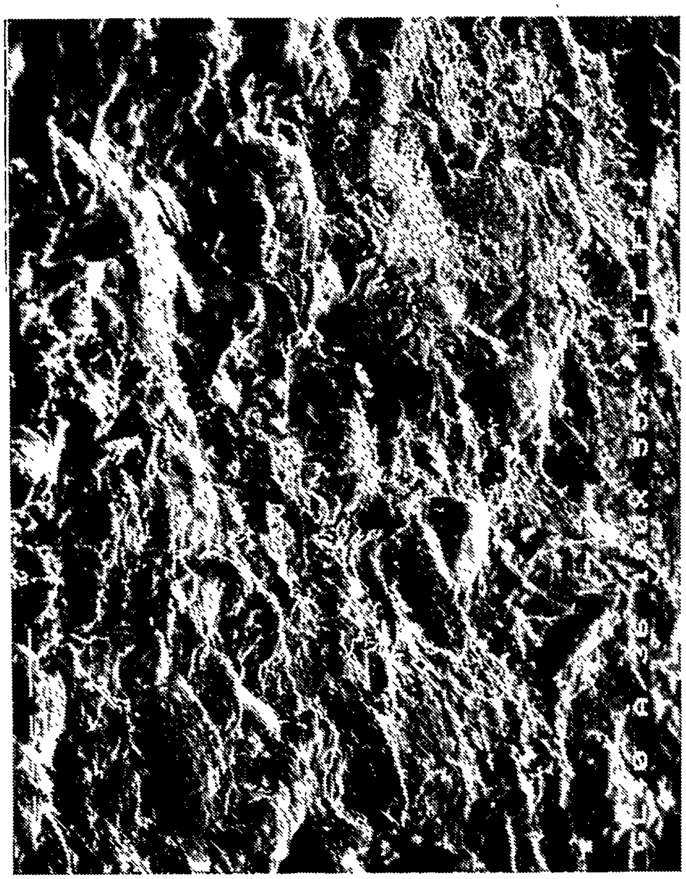
Of the instruments recommended, the Testex and magnetic snap-off gage more closely measure roughness. Of these two, the magnetic gage measures exactly the same area as the routinely used paint thickness gage because they are, in fact, one and the same. Therefore, because paint thickness is probably the most agreed upon paint performance determinant, it would stand to reason that the magnetic gage would be the best instrument to use. At least, assurance would be given that the peaks have been completely covered during painting. Further to this argument, the normal magnetic thickness gage should he used to measure roughness without adjusting the scale. This procedure would then be in complete agreement with the SSPC procedure for measuring film thickness in that the magnetic gage is used to measure the surface profile prior to paint application. This number is then subtracted from the measured dry film thickness of paint to obtain the actual dry film thickness.

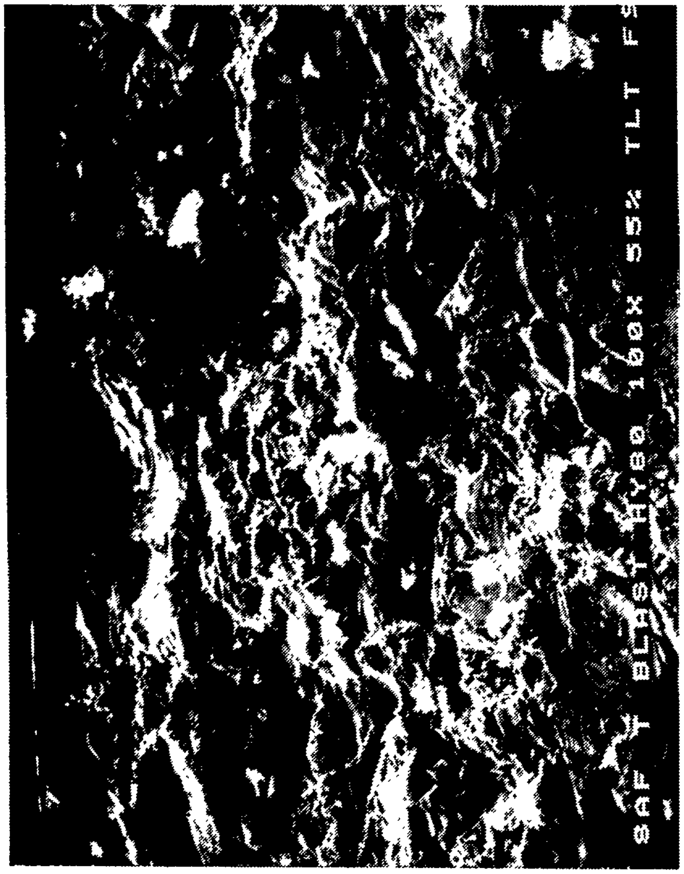
This proposed procedure is simple, straight forward, and requires no interpretation and no procurement of expensive equipment.

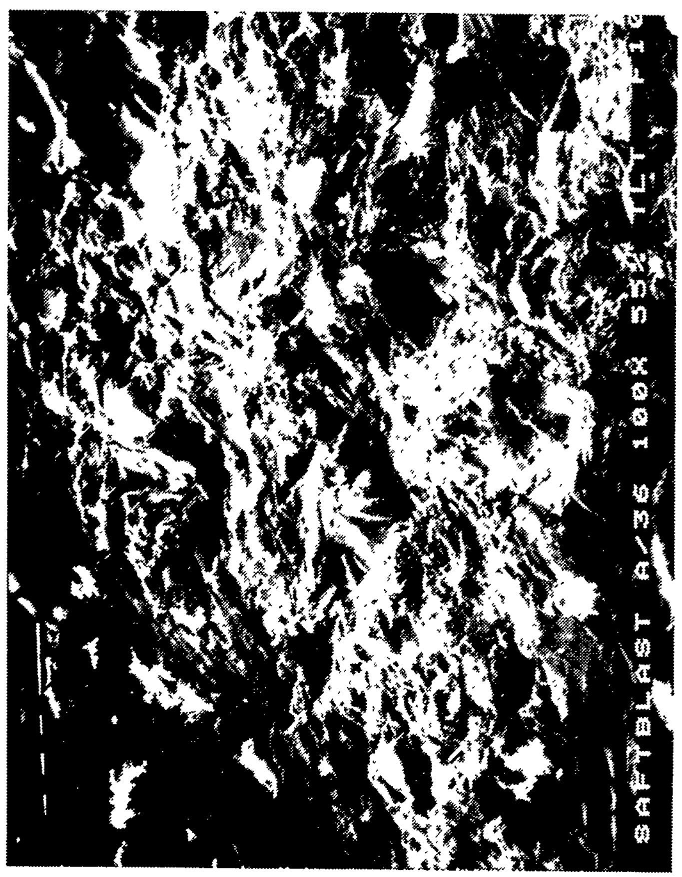
ANNEX A

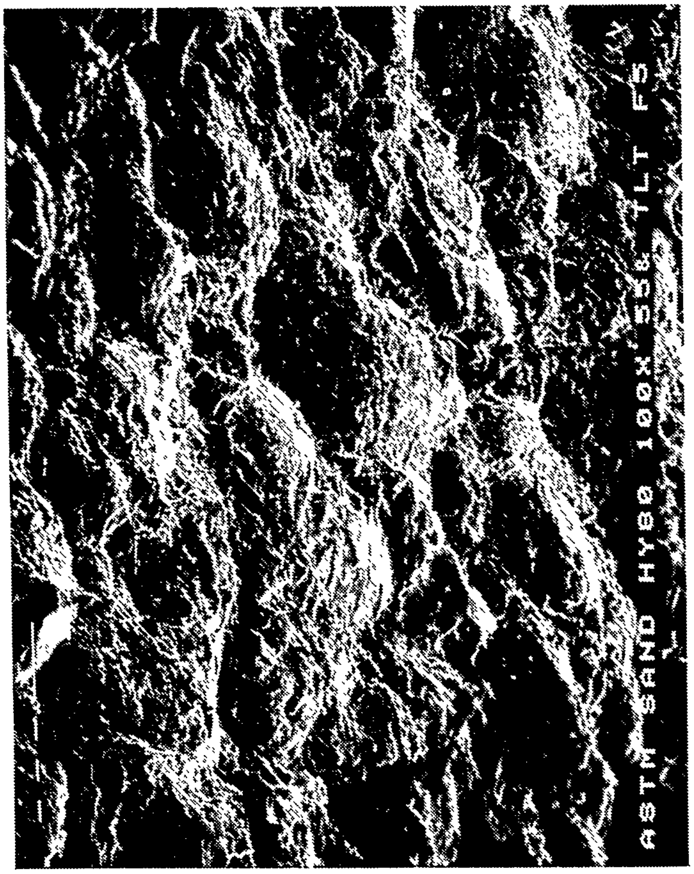
Scanning Electron Microscope Photographs
of
Various Surface Textures

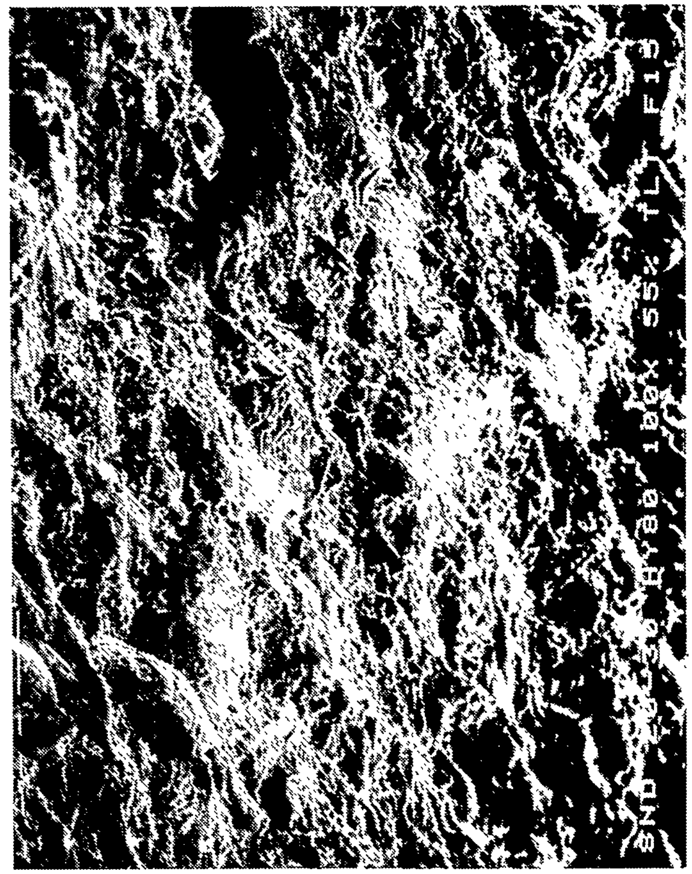


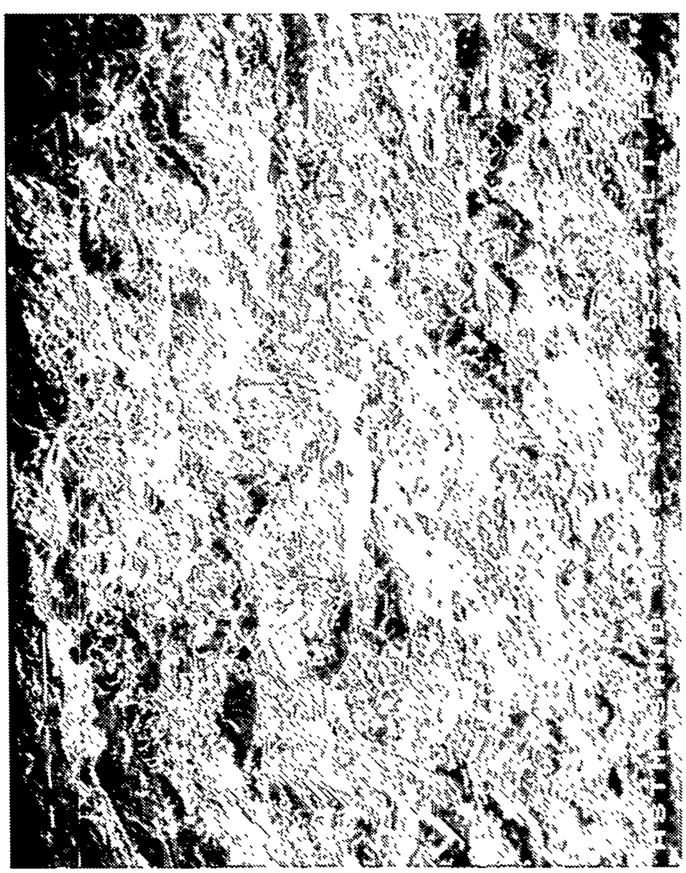


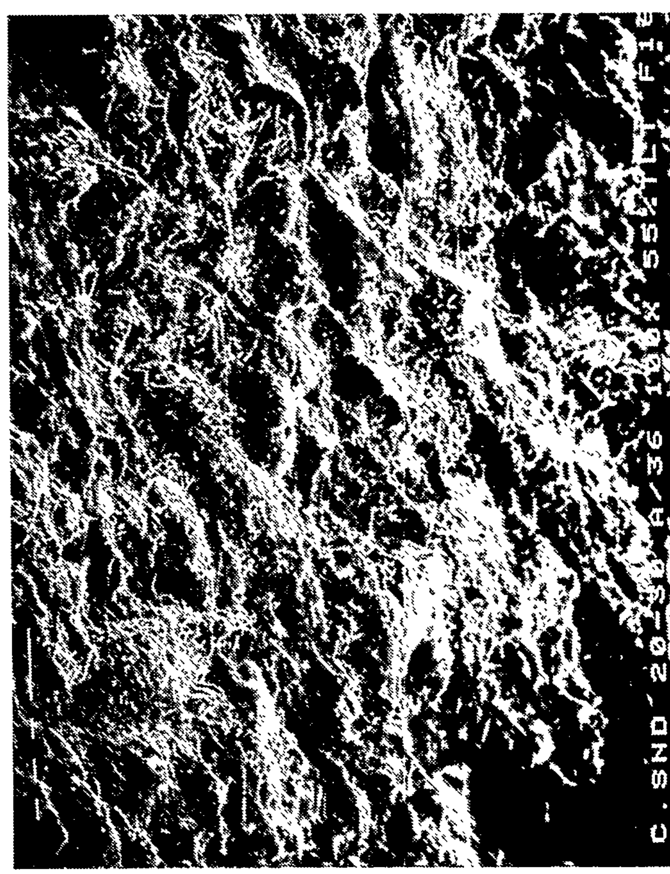

SAF T BLAST HY80 100X 55% TLT

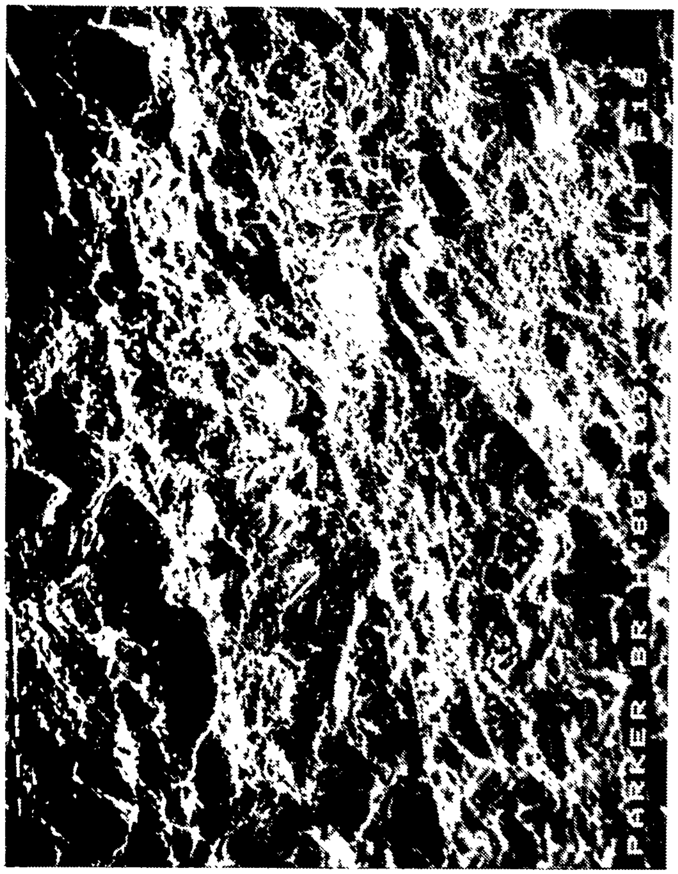

SAFTBLAST A/36 100X 55% TLT

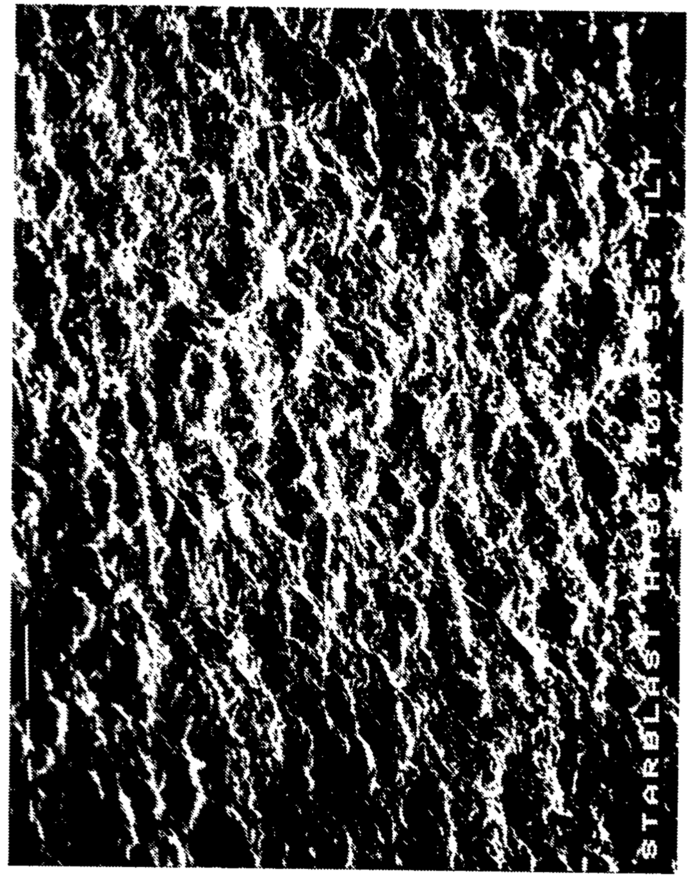


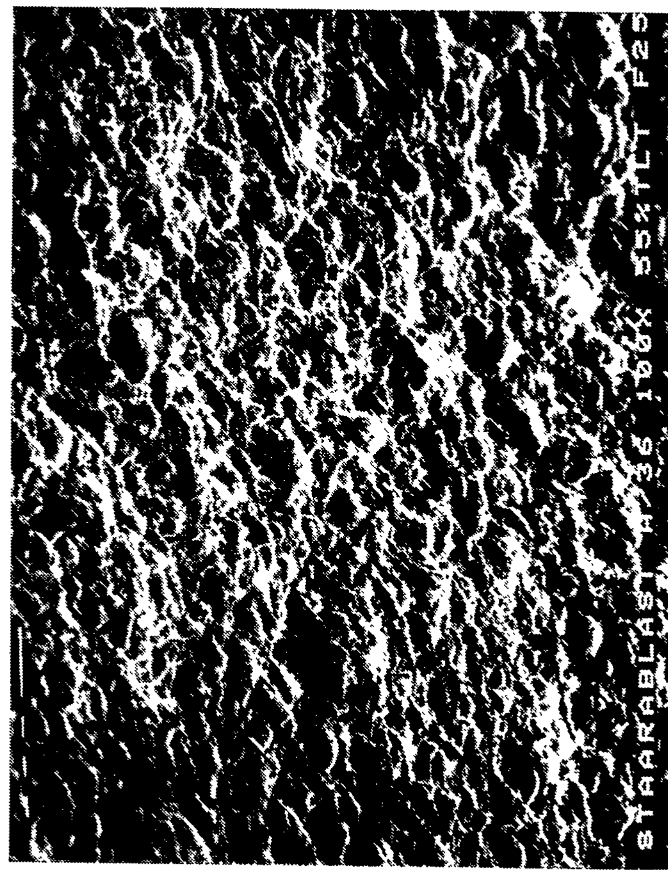


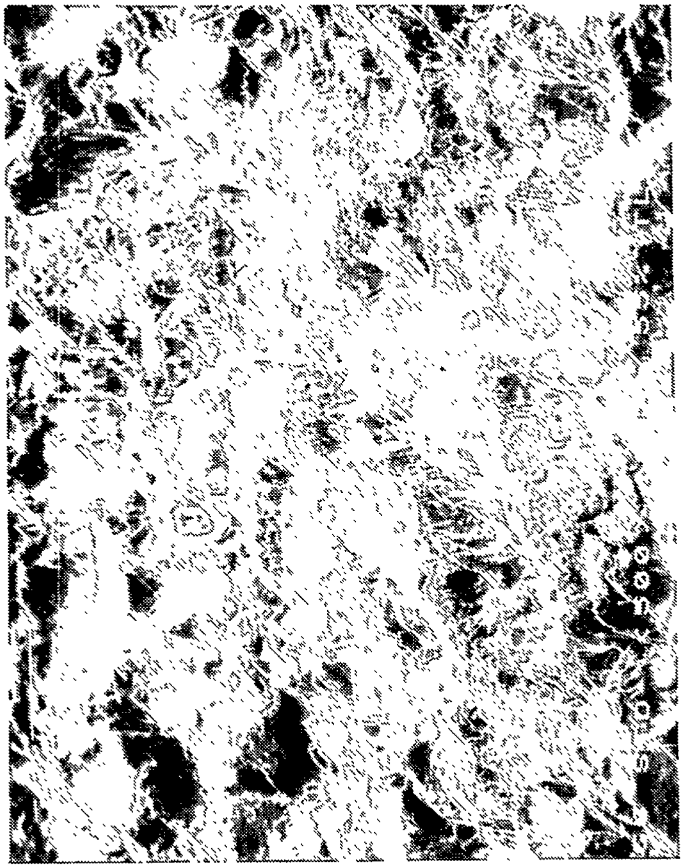


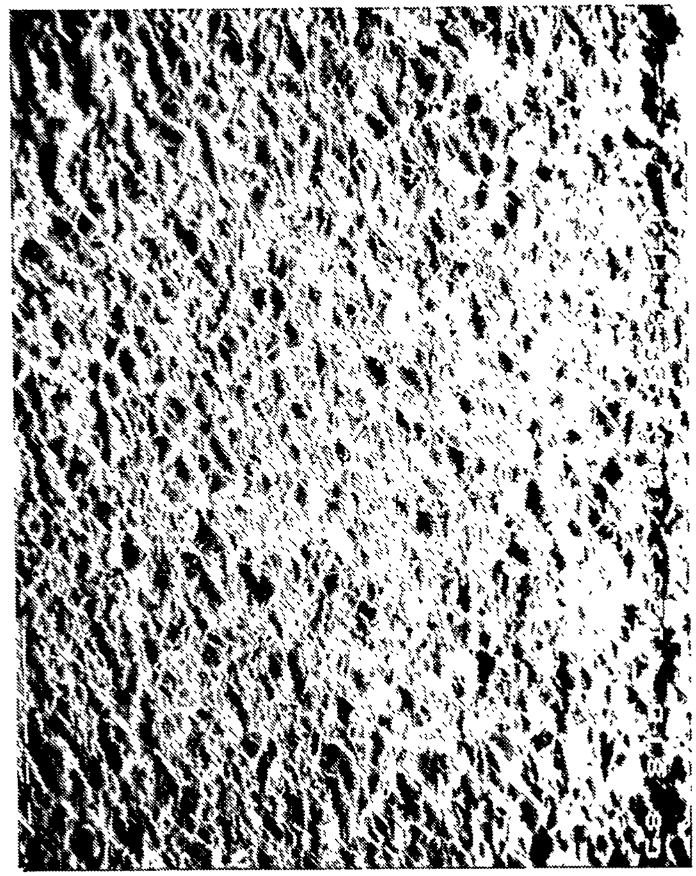


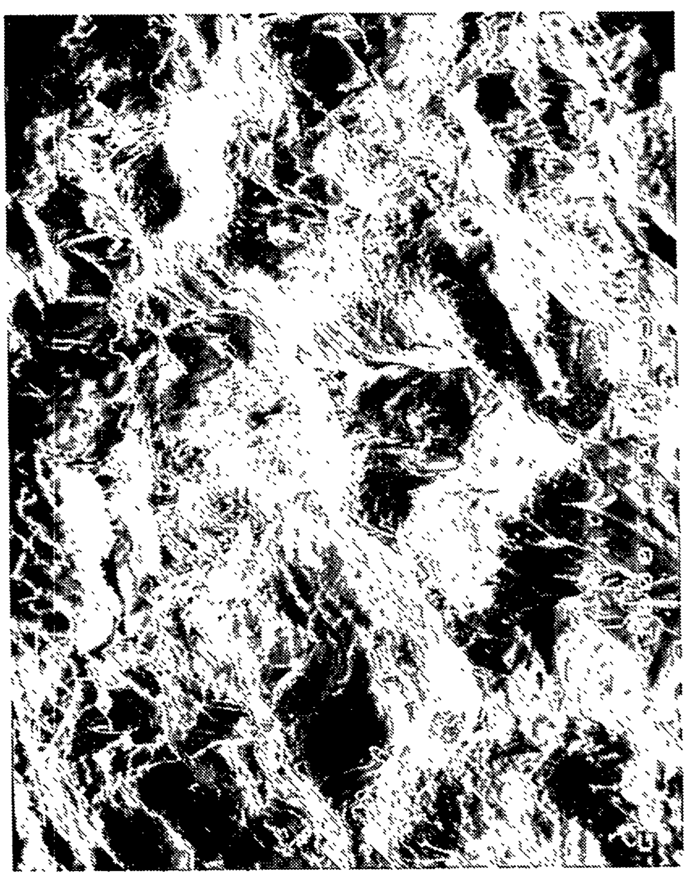


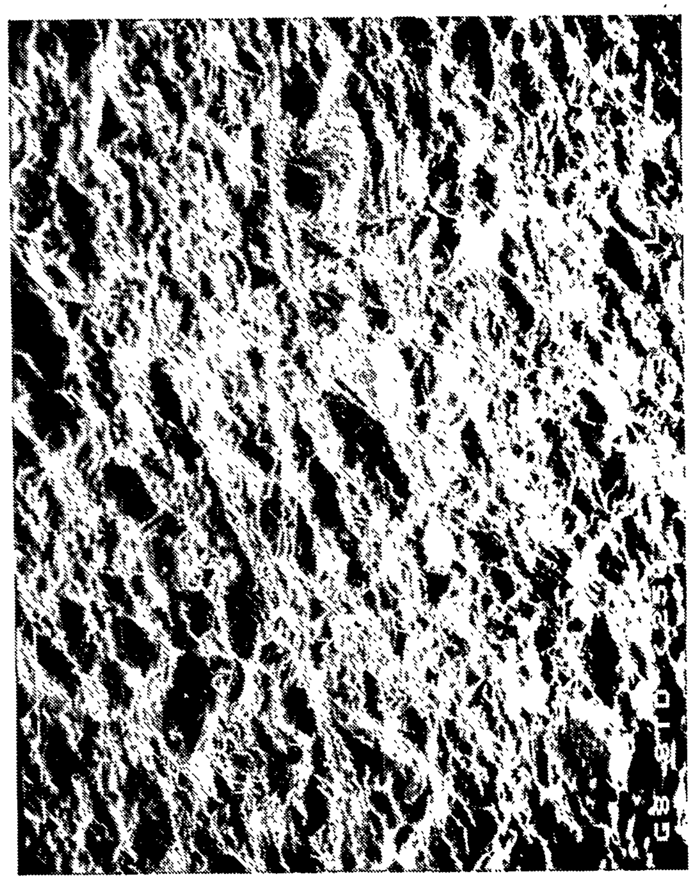


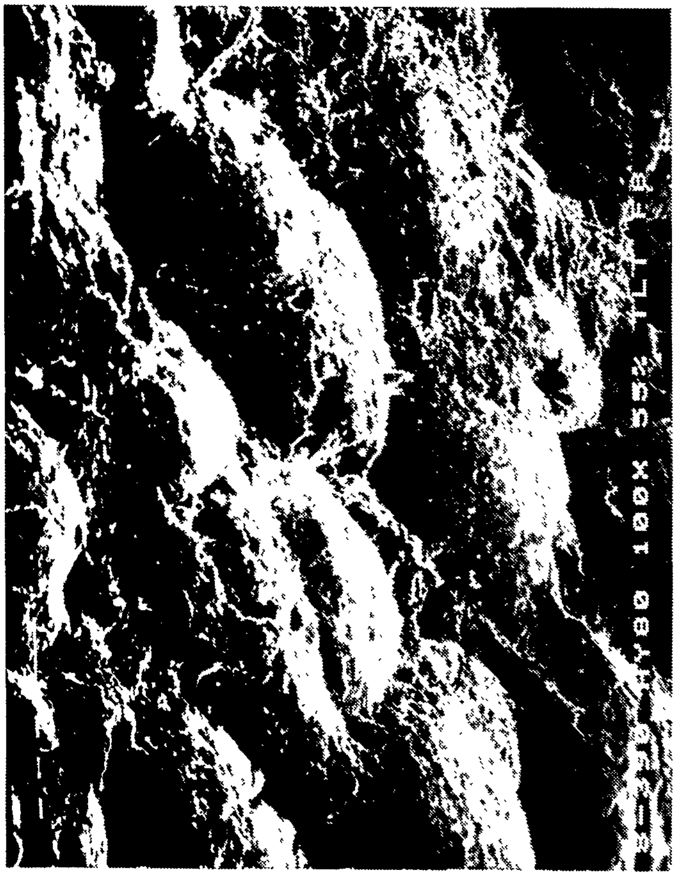


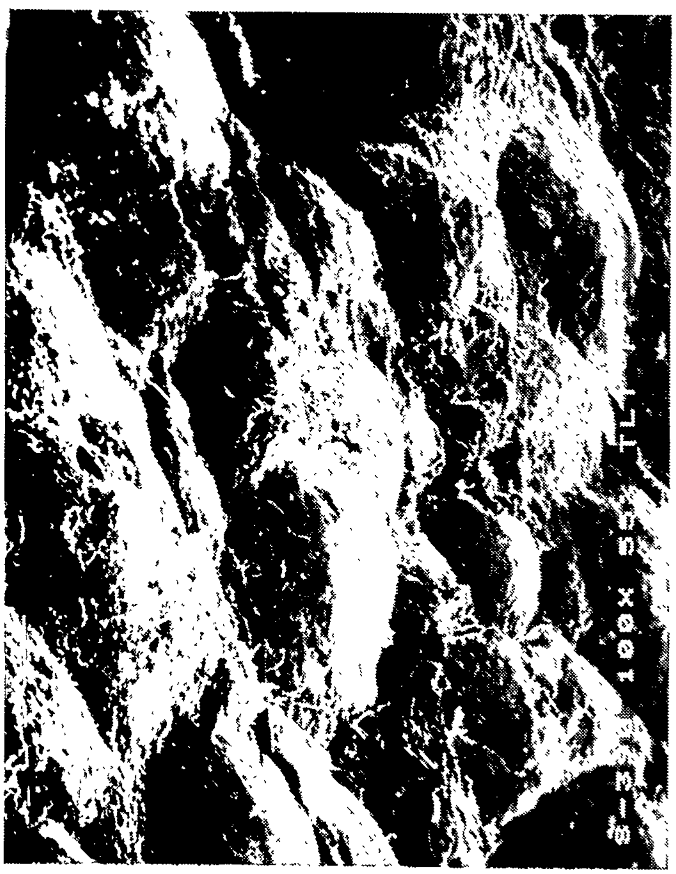


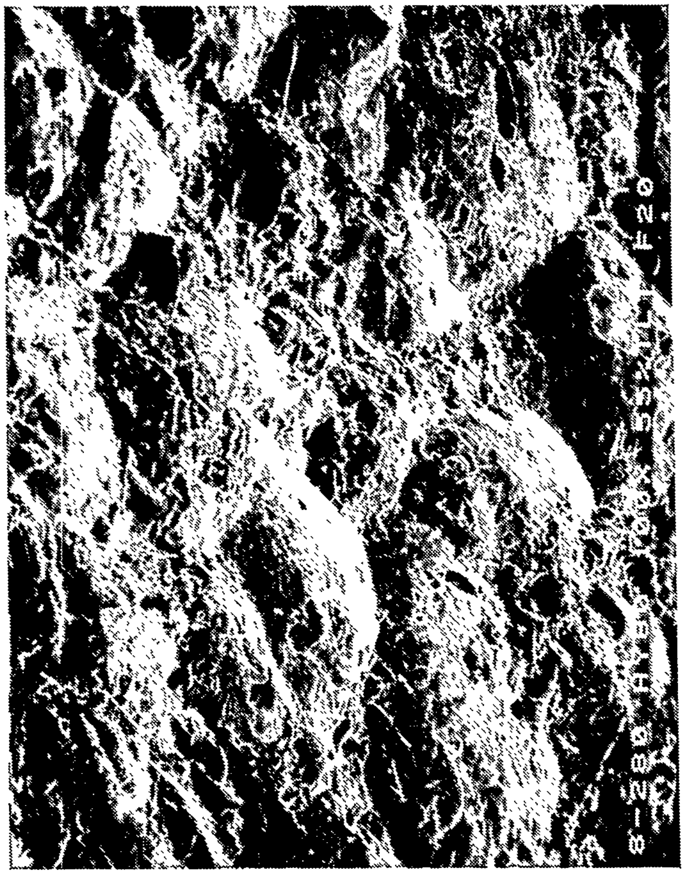


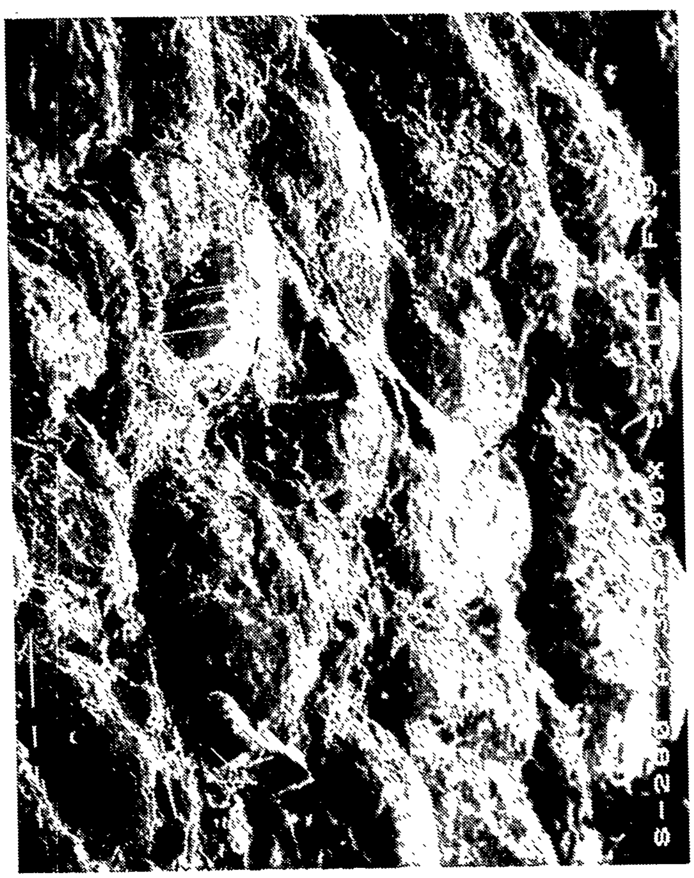


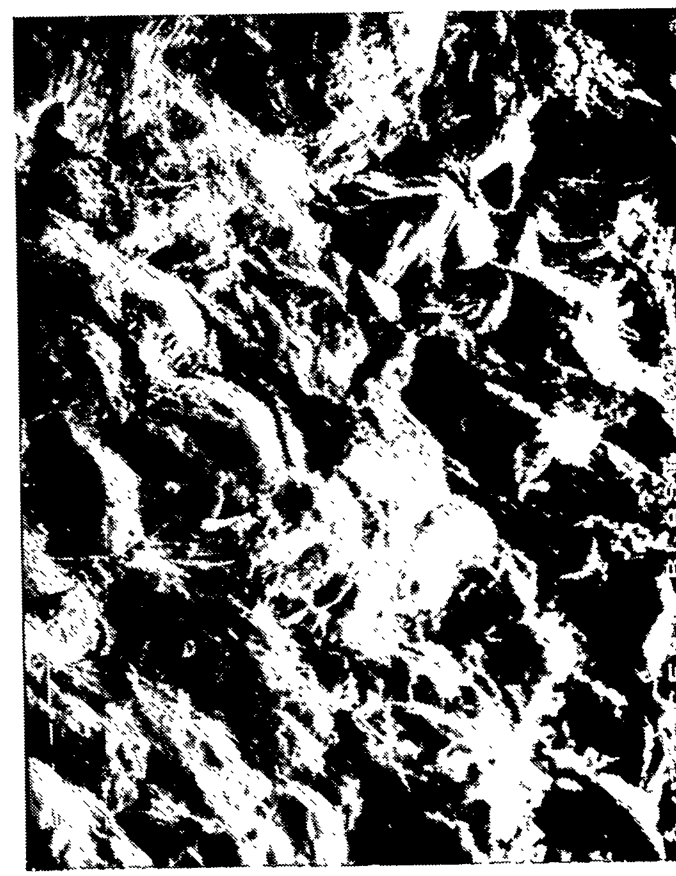


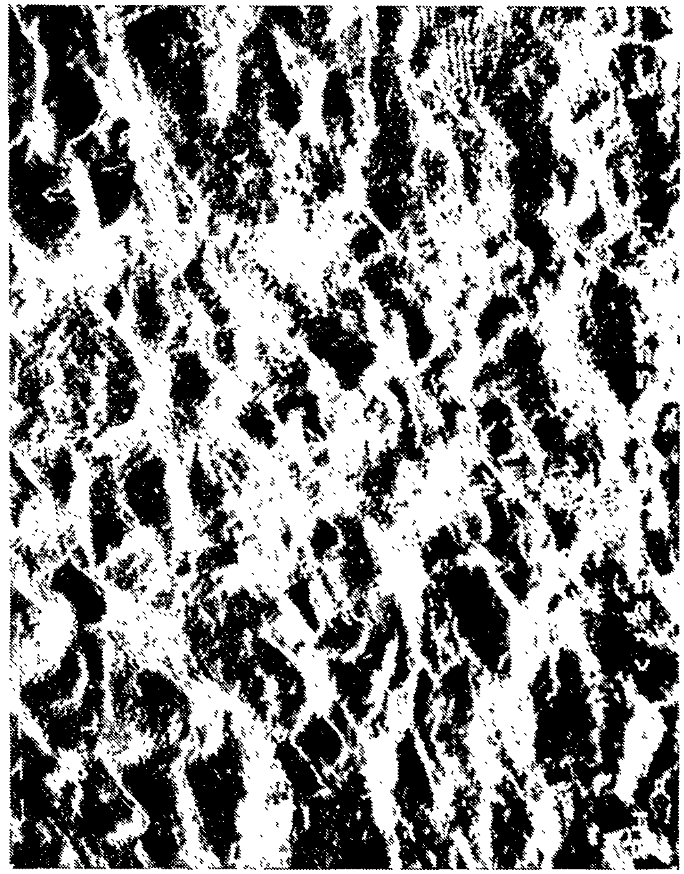




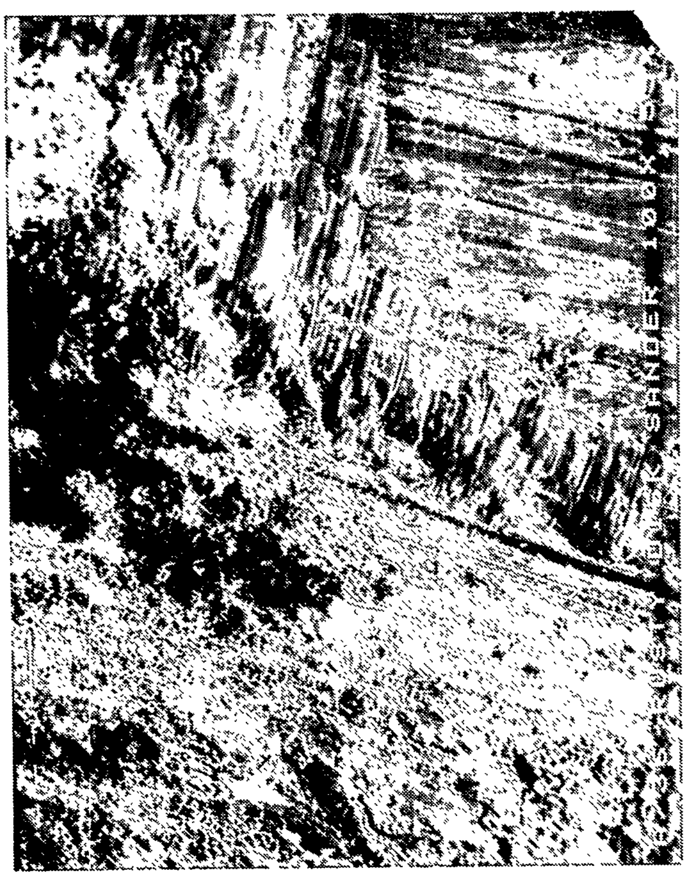









HY80 PAINTED DISK SANDER 100X 55%



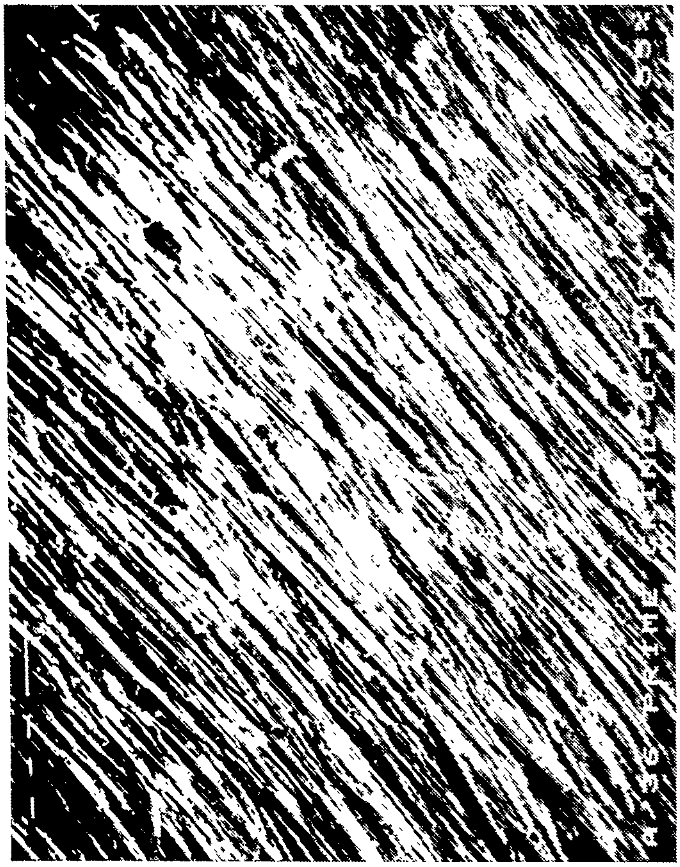

HY80 RUSTY DISK SANDER 100X 55%


HY80 NEEDLE GUN PRIMED 100X 55%

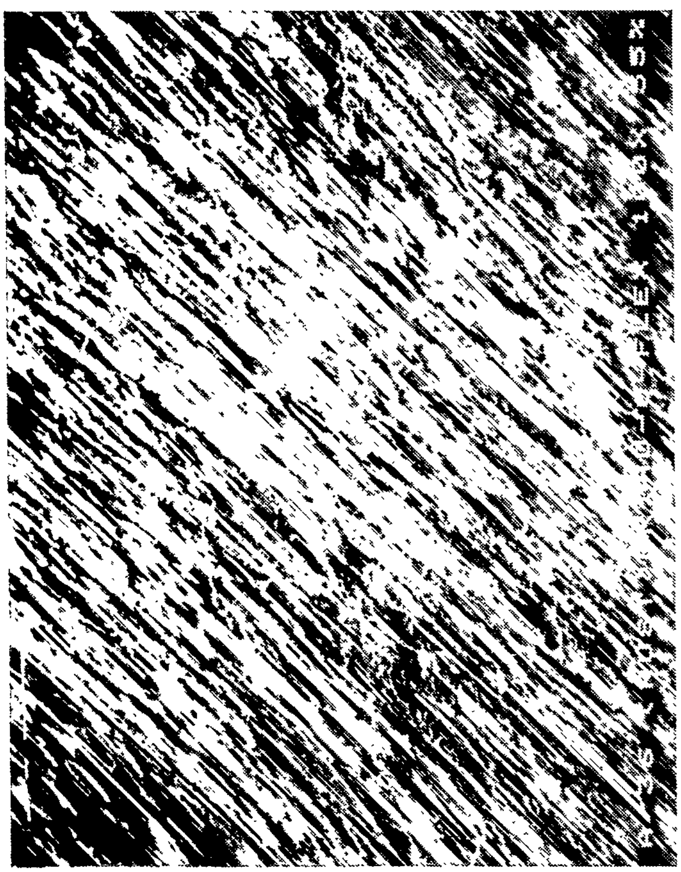

A/36 NEEDLE GUN RUST 100X 55%TLT

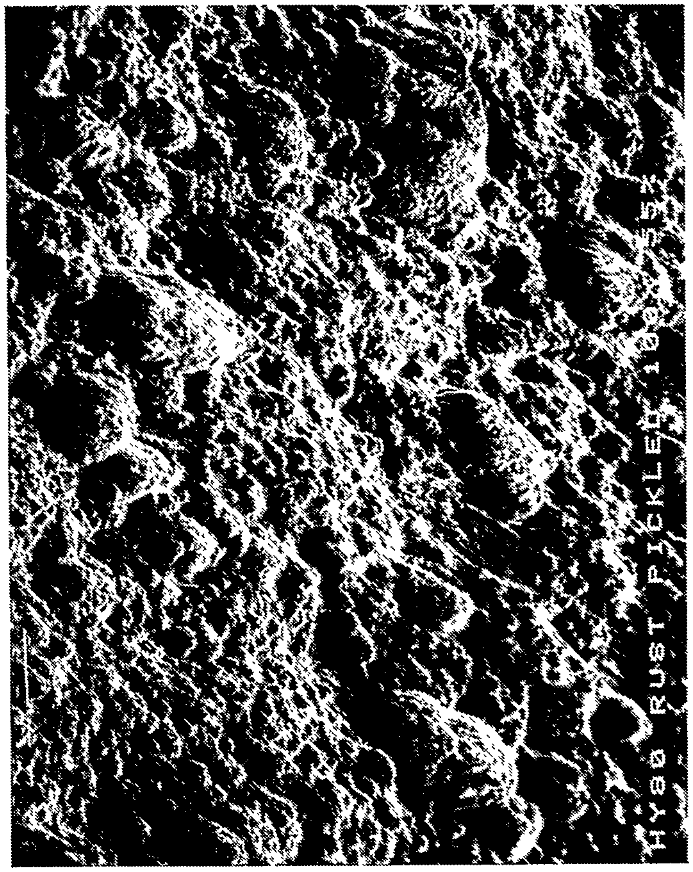

HY80 RUSTY NEEDLE GUN 100X 55%

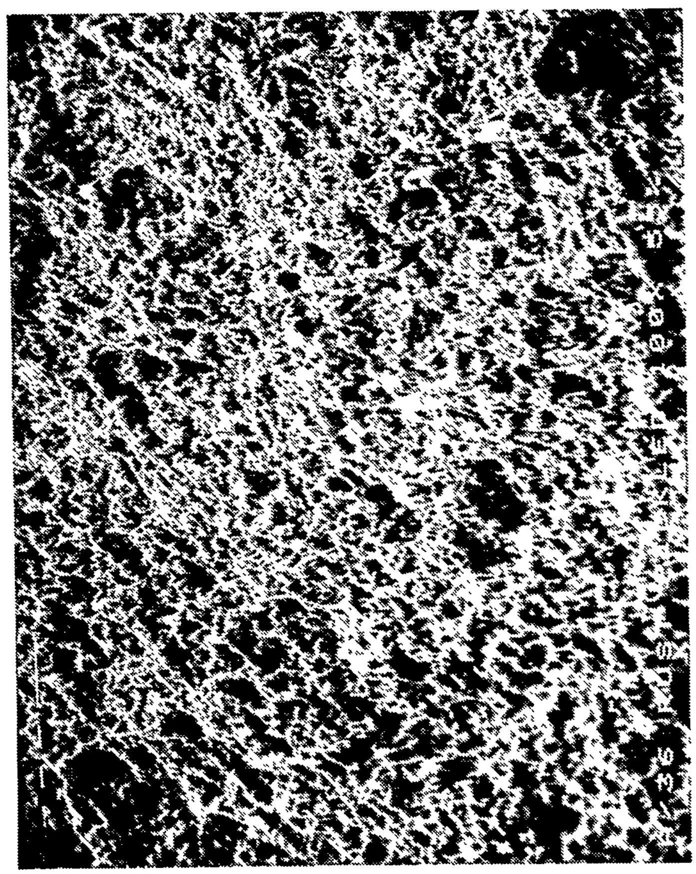

HY80 PRIMED WIRE WHEEL 100X 55X




HY80 PRMD GRIND-O-FLEX 100X 55%




HY80 RUST PICKLED



ANNEX B
Bibliography

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